MINUTES OF PROCEEDINGS

OF THE

INSTITUTION

OF

CIVIL ENGINEERS;

WITH

ABSTRACTS OF THE DISCUSSIONS.

VOL. XII.

SESSION 1852–53.

EDITED BY

CHARLES MANBY, F.R.S., M. INST. C.E.,
SECRETARY.

INDEX, PAGE 613.

LONDON:
Published by the Institution,
25 GREAT GEORGE STREET, WESTMINSTER.
1853.

LONDON: PRINTED BY W. CLOWES AND SONS, STAMFORD STREET AND CHARING CROSS.

ADVERTISEMENT.

THE Institution is not, as a body, responsible for the facts and opinions advanced in the following Papers read, or in the abstracts of the conversations which have occurred at the Meetings during the Session.

CONTENTS.

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1852-53.

November 9, 1852.

JAMES MEADOWS RENDEL, President, in the Chair.

No. 879. "On the Improvement of Tidal Navigations and Drainages." By WILLIAM ALEXANDER BROOKS. M. Inst. C. E.[1]

THE chief object of this Paper is to afford, to members of the Institution, an opportunity of offering their observations, and to elicit from nautical men the narration of facts, which may be hereafter usefully employed, in "a further investigation into the laws which govern the flux and reflux of the tide in estuaries;" a subject more adapted for men possessing the highest mathematical and philosophical attainments, than for those who must restrict their labours, to recording the practical observations made in the course of their professional engagements.

No branch of science has more serious impediments thrown in the way of its practical application, than River Engineering; and nowhere is there to be encountered a larger array of popular prejudice, than in the execution of works involving an interference with the natural condition of tidal rivers; an inconvenience generally arising from limited information, on the true physical features of the navigations in question. While constructing works for the improvement of rivers, where the chief object is to throw into the channel of the river a greater volume of water, at a given time, or to fill, more completely, the space between the banks, the Engineer is met with the statement, that

[1] The discussion upon this Paper extended over portions of two evenings but an abstract of the whole is given consecutively.

"every shovelful of material, put into the river, must necessarily cause an equal abstraction in volume of tidal water, for which there is no equivalent," and that to this proposition no exception can be found in Nature, is the general opinion of those who oppose any interference with the natural condition of rivers.

In the course of twenty-five years' practice, chiefly on fluvial and maritime works, it has been the Author's lot to encounter so much prejudice, and opposition, based on these erroneous views, that he has felt it to be a duty to endeavour to refute them, and to show with how little judgment the cry is often raised, against what are popularly, but erroneously, called "encroachments upon navigations," or "abstractions of tidal water."

As the popular prejudice, against river works, arises from the supposition, that all tidal receptacles possess similar features, or are in the same condition, it will be advisable, first to call attention to the difference which exists in the physical conditions of tidal rivers.

Estuaries may be divided into two classes. Those of the first class are bounded by shores very gradually receding from each other, as they approach the Ocean; as in the cases of the Thames, the Humber, the Gironde, &c.

In such rivers, the navigable channels bear a large proportion to the full breadth of the stream, at the time of high water, whether at a spring, or a neap tide.

These rivers afford the most perfect drainage to the country, because they offer a capacious low-water channel, which allows an immediate means of escape and subsidence of the floods.

There is also a very gentle declination of the surface of such rivers, at low water, and consequently only a slight diminution, or loss of height, in the tidal column, as it advances up the channel. The transmission of the tidal wave is therefore quick, as the flood rapidly attains sufficient head to turn back, or overcome the current of the ebb, and the interval of stagnation, or rest, is, as at sea, exceedingly short. One of the best tests of the condition of each portion of a navigation, is to be found in the duration of the intervals of still water, between the flood and the ebb, and *vice versâ*, the navigation being in a good state, when these intervals are short, or approximate to those which are observed at sea.

Rivers possessing the features previously described, will be found to be comparatively free from bars in their channels, as well as at their mouths, and where any material diminution of depth is found, it may be traced solely to one of the following causes; viz., either to a division of the main stream into two, or more channels;—to an abrupt change of the course of the current of the ebb;—or to the flood current not running in the channel, previously occupied by the ebb tide. The latter case will, however, be seldom found, where the shores are naturally of a well-regulated form, both currents being generally compelled to occupy the same channel.

At the mouths of these estuaries, there will not be observed any considerable opposition to the young flood, except during the discharge of very violent land freshes. The wide mouth and gradually narrowing channel also influence that elevation of the tidal high-water surface, above the sea level, where the run of the tidal column is sufficiently long, to have attained the necessary momentum.

Estuaries of the second class present features directly opposed to those already described, as they will be found invariably to have a great disproportion of the relative widths of their channels, when measured at low water, as compared with their widths at high water; so that the bed offers a much greater resistance, or friction, than is found, where the channels have greater depth and uniformity, as in the first-class estuaries. They have also a greater fall, or declination of the stream, at the period of low water, and a consequent rapid loss of height in the tidal column, as it progresses up the channel, so that the stream soon loses its tidal character. This feature causes a considerable interval of rest, between the currents of the flood, and the ebb, not only at the mouth of the river, but at all those places, where the fall, at low water, is rapid, so that the stream may be considered to be divided, at low water, into a series of pools, separated by rapids, or natural weirs, which obstruct the discharge of the land waters, as well as prevent the admission of the tide.

During this interval of stagnation, or while the young flood is acquiring sufficient head to overcome the stream, over these rapids, the technical description of the state of the tide is, that it is "merely swelling;" and it is during this period, that the greatest amount of deposit takes place, whether brought in from

the sea, by the flood tide, or down the river, by the current of the ebb.

From the presence of these obstructions, the velocity of the tidal column is much diminished, beyond that which is due to it, from the flow at sea, or the head, which would give a much greater velocity to the column, in a river of the first class, and therefore, even near the mouth of the river, the current will continue to run in, although the ebb has long made at sea. The receptacle is in fact not filled, and there must, therefore, exist a great difference, between the time of high water on the bar, and at stations up the river, the proper time of high water being defined, at the instant when the rise ceases to be perceptible. The head of the tidal column does not attain a higher range than at sea, and where features exist, offering considerable obstructions, the level of the river, at high water, does not even attain to that of high water at its mouth.

In this class of rivers, the shallowness, as well as the great excess of breadth, in proportion to the amount of their discharge, is due to the early flood current forming lateral channels, where the stream of the ebb runs with less force, than in mid-channel, and where the flood, meeting with the least amount of resistance, will force its way. Hence the formation of what are called flood-tide channels, or 'swatchways,' up which a passage may be made, while the ebb, in mid-stream, still runs too strong to be contended against without great labour. Through these channels, which are constantly varying in direction, a portion of the current of the succeeding ebb is discharged, occasioning a manifest loss of power, which would be available, if properly directed, to keep open a good main channel.

From this cause, also, arises the difference in feature, as to breadth compared with depth, which distinguishes a river in a naturally good condition, and in which tidal encroachments would prove injurious, from another, in which contractions of its shores may judiciously be made, with the view of removing the obstructions in its bed. Such improvements would have for their object, to enable the tide to flow up the channel, with the height due to it, from the rise at sea, after allowing a small slope to exist at low water; but this latter will be found to be very slight, except where the river course is extremely tortuous and its bed rises rapidly. In rivers, whose courses require to

be trained, the low-water sectional area will be found to bear only a small proportion to the high-water section. It is unnecessary to dwell upon the increased resistance to the current, produced by this disproportionate width of the channel and the rapid rise of its bed.

In this class of rivers, there is always an excessive enlargement of the channel, on approaching the sea, which is never found in rivers of the first class, even although draining a vast extent of country. Where the slope, or declination of the low-water surface, is very great, this enlargement extends only for a short distance inland, and the tidal character of the stream soon ceases, but in first-class navigations, the tidal influence, or enlargement of the channel, due to the addition of the tide, extends far inland, and it becomes difficult to define where the character of an estuary, or tidal river, ends, and that of a fresh water stream begins. Thus it is, that in a river approximating to a perfect state, there exists, in the lower reaches, a receptacle for the land floods, of such ample extent, as to prevent that confliction which would otherwise occur, at the mouth of the river, during the flood tide. And thus also it is found, that in bar rivers, such confliction is, during land floods, sufficiently powerful to prevent the formation of an upward current, the head acquired by the land stream, rising faster than the flood tide, during the whole time. This has often been considered as an advantage to the river; but it is in reality the worst state of the navigation, inasmuch as the benefit of the land floods, or their scouring influence, is weakened by the increased duration of the period in which they are discharged. Where, however, the river approximates to a perfect state, the drainage of the district is arrested, at such times of heavy floods, solely during the true, or oceanic duration of the flood tide, and is discharged, on the ebb, in the smallest possible time, and, consequently, with the greatest power to maintain a deep channel and efficient drainage.

It is to this great tidal influence, in accumulating the volume of water arising from heavy land floods, that such a wide difference exists in the navigable advantages of such rivers, over those which are discharged into tideless seas, or where a very slight rise of tide is felt. Thus the great Mississippi, from being discharged into the nearly tideless Bay of Mexico is, as

regards its navigable condition for sea-going vessels, far inferior to the Thames, the Humber, or the Shannon; and the produce of the valley of the Mississippi is generally conveyed in small coasting vessels, to New York, and other ports, to be from thence conveyed, across the Atlantic, in ships of a greater draught, than are able to cross the bars at the mouth of the Mississippi. These second-class rivers, are, in fact, channels which are inefficiently drained, or discharged, and are consequently imperfect as tidal receptacles.

It is therefore evident, that in these examples, the construction of works, which have the effect of depressing the bed, and consequently the level of the river at low water, must increase the depth of the tidal receptacle,—the most useful element of its capacity,—whilst the power of the discharge of the drainage will be also augmented. Numerous instances may be adduced, of such expansions of the shores of estuaries, which, although forming large tidal receptacles, are nevertheless injurious, in their effect upon the navigable condition of the channels. Many of these vast expanses retain a tidal character, in consequence of the drainage of the country passing through them, in channels which vary in their course; for although a short time suffices for the accumulation of sand-banks, up to the level of half, or three-quarter tide, yet a long period is required, to raise such tracts to the state of alluvial lands, the later deposit being of a lighter character, as compared with the former, which consists principally of marine sand.

It may be received as an axiom, in using walls to give a fixed course to channels through estuaries, that although they may be raised only to the level of half tide, they are quite sufficient to determine the future condition of the spaces enclosed behind them, as the conversion of those spaces into available land, is simply a question of time, and of the amount of alluvium brought down by the floods. Thus half-tide walls will, eventually, produce the same effect as full-tide walls; it is, therefore, a mistake, to imagine that such works can be constructed, and that the tidal receptacle behind them can be at the same time retained.

Encroachments upon, what may be described as, harbours of purely tidal character, should not be permitted, as it is manifest, that the depth in their channels, must depend entirely upon

the amount of backwater, which, in those harbours, can never cause a conflicting action of the sea and land waters. In such tidal harbours, every enclosure, by breakwaters, or piers, should also be carefully considered, it being evident, that the construction of such works must have a tendency to create a deposit, by the diminution of the power of the returning wave, or backsweep.

It is sometimes stated, that "the difference between the relative times of high water, affords a true test of the condition of a river;" but this should be received with caution, as the only certain test is the condition, or progress, of the tidal wave, throughout the entire period of the flow. Thus the tidal wave, in a broad and straight reach, will pass more quickly through it, after the sands are well covered, although, in the earlier stage of the tide, its progress may be extremely slow, from encountering banks of sand, which force it into a tortuous channel, till the water rises above them, and a ready course of transmission is afforded for the tidal column.

A difference of level will be found to exist in the early flood tide, between the surface of the water, at the head of the lateral channels made by the flood tide, and that in the main channel, abreast of it, where the flood is repelled by the superior head and momentum of the ebb: during this period, or before the flood tide overruns the separating banks of sand, the flood tide filters through these sands; hence it is that "sand-banks are alive on the flood tide, and hard on the ebb." The same observation, as to the effect of the flood tide, is also true with regard to those sand-banks, lying in situations out of the reach of the strength of the ebbing water, or being, in fact, situated in eddies, created by the course of the ebb alone, but yet exposed to the full set, upon them, of the current of the flood tide, which produces a visible scouring effect upon them; and this leads to exaggerated notions of the power of the flood tide, or that it exceeds that of the ebb. Nothing can, however, be more incorrect; observers frequently forgetting to notice, that every part of the channel, lying in the true run of the ebb tide, is clear of sand-banks, and that while the scouring effect of the ebb continues during the whole of that tide, the scouring effect of the flood only commences, when the current has attained sufficient head, and consequent velocity, to overrun the ebbing

water. Hence the height of these sand-banks is governed by the strength of the eddy, on the ebb.

There is a very popular fallacy, as to the greater utility of the flood current, over that of the ebb, in deepening the beds of rivers, and it has even been sanctioned by Engineers of experience, and undoubted talent, who have been led into the error, from, it may be presumed, insufficient, or ill-timed observations: the following extract from a recent report is an example:—

"It must be remembered, that the preservation of a navigable channel, here depends, solely, on the scouring effects of the tide, and the admission of the greatest possible quantity of water from the sea. This is the species of backwater which is to be sought after, and not that which may be termed a head, or dam of water. A somewhat general notion prevails, that the scour is produced by the fresh water of the river, and consequently, that the ebb tide is the great agent, in stirring up the sand from the bottom. Whenever the tide has a considerable velocity, these matters are found to be in a state of motion, as if boiling up from the bottom, while during the ebb tide, the water is comparatively pure, and the deposit, which it is unable to carry off, settles at the bottom, to be again disturbed on the return of the flood tide."

It is evident, that the above opinions are grounded upon observations made upon sand-banks, of the nature previously described in this paper; and it is only necessary to show the insufficiency of their foundation, by reflecting, that if the facts were really as stated, then all rivers must have long since been filled up,—the only action of the flood being inwards.

Tidal observations demonstrate, that no advantage to the navigation is gained by the water being allowed to expand, or to fill the irregularities which often exist in the line of the shore, and that, in fact, the energy of the tidal column is wasted, in filling those bays, or indentations. Alarm is created, by the mere proposition to embank such mud lands, from the belief, that there will necessarily ensue a diminution of the body of tidal water to be thrown into the river. This is, however, a very superficial view; as, in reality, in the examples where these cases of irregular expansions and contractions exist, it must be remembered, that the channel consists of a series of

pools, separated by rapids, or natural weirs; the deep water in those pools being in a comparatively inert state, during both the flood and the ebb tide, and in fact that inert water occupies space, which would otherwise be filled, on both flood and ebb, by an energetic current, if those shoals, or weirs, were removed and a well-regulated bed, or channel was established, which latter can never exist, in connexion with irregular shores. In such an amended state of the channel, the entire mass of water, from the bed to the surface, would be in motion and would possess, what Guglielmini describes as, "the energy of deep water," which attribute is only to be found in channels free from these natural weirs, or bars.

In estimating the power of a stream, passing over a well-regulated bed, the full height of the column of water above it, may be considered as effective; but in a stream, where deep pools and shoals exist, the power can only be calculated upon, by the depth of the water over the natural weirs, or bars; and indeed, this latter amount exceeds its real value, as allowance should be made for the loss of power which the current experiences, in having to communicate motion to, and to draw with it, the inert mass of water, lying in the pools at low water. It is evident, that this injurious effect is produced, also, on the ebb, or impedes the natural drainage, and may be considered to resemble the discharge of a scouring reservoir into and through a deep pool, or basin, the whole of whose contents, if previously existing in a stagnant state, must be put into motion, before any useful scouring effect can be produced, upon any bank of sand outside.

The tidal energy, or power, of a deep-water navigation, may therefore be greatly superior to that of a shallow one, although the latter may be of greater area, as a tidal receptacle, and may possess an equal rise and fall of tide at its mouth. In the former example, or that of a deep-water navigation, contracted within proper bounds, the entire cubic content of the receptacle, will be nearly filled, by the tide, at the time of high water; but in the other, the ebb will have fallen considerably on the bar, long before it is even high water, at only a few miles above. In the one case, the receptacle is well filled; in the other, it is never properly emptied, nor is the space above it ever effectively occupied by water, so that extensive lateral

enclosures may be made, without really diminishing the effective tidal volume.

The mass of tidal water received by these shallow rivers, is of a wedge form, whose vertical dimensions are included between a line formed by the surface of the water, at the instant of low water on the bar, and another line, consisting of the surface of the tide, at the instant of high water on the bar. Bearing this fact in mind, it is not difficult to conceive cases, where the tidal receptacle may not be half filled.

In the cases where reclamations of shallow portions of the channels have taken place, involving an apparent diminution of the tidal receptacle, it should be borne in mind, that such parts are only occasionally covered by the tide; whereas the augmentation of the tidal receptacle, which takes place by the depression of the low-water surface, is felt at every tide.

In thus pointing out the leading features, of a good, or a bad state of navigation, the proper means for remedying the latter, are naturally suggested, and it is unnecessary, to make any observations, beyond saying, that the Author's own practice, in training the current of a river, consists in first constructing full-tide timber groynes, or jetties, at right angles to the course of the intended new line of river frontage, and which he has found to cost from twelve to thirty shillings per running foot. These structures have been very aptly described by Sir William Cubitt, as "the scaffolding for forming the new line of shore," as they "make so much more land, and bring the shore to the form represented by a line drawn through the ends of the groynes." This latter extract, refutes all that has been advanced against such works, from their immediate action producing irregularities, or holes, close to the ends of the groynes. This effect does take place for a time, but it must necessarily cease, with the existence of the eddy which produces it. The irregularities only exist, while the spaces between the groynes are being converted into land. It is however equally true, that the almost immediate action produced by these groynes, is a general equalization and deepening of the bed of the river, which is also effected far more economically, than by the construction of parallel walls of rubble. The Author considers, that these latter should not be constructed, until the jetties, or groynes have had the effect of raising the

level of the bed, on which the rubble walls are to be placed. By this means, an immense saving of material may be effected. Cases however do exist, in which it is more advisable to commence by constructing parallel walls, as in the example afforded in some very wide estuaries, wherein embankments are to be made. The construction of parallel rubble walls, insures a certain amount of immediate success, due to the contraction of the breadth of the channel, although that system does not possess the recommendation of being the best which can be adopted, to obtain the greatest extent of future navigable advantages, at the smallest cost.

By the system adopted by the Author, there is scarcely a river, whose navigable capabilities may not be greatly increased, by the outlay of, frequently, only a few hundred pounds, and in a manner which renders the advantages almost immediately perceptible.

As regards the influence upon the drainage of a country, by works constructed for the improvement of navigations, the Author considers, that this subject has not received the attention which its importance merits. Drainage works have, unfortunately for the country at the back of them, been generally undertaken merely to serve immediate local interests, and it is thus, that although many highly useful local works have been executed in the fen districts, they have not been planned with a due regard to the interest, or the proper drainage of the country, more remote from the sea; and thus the available resources for an efficient drainage, have been frittered away, by a system of small, or local works. In fact, no great artery has been preserved, to give a healthy circulation to the general drainage, and if the interests of navigation had been made paramount, the true interest of the land-owner, in having an efficient and inexpensive means of drainage, would also have followed. Much greater progress would have been made, towards establishing a general efficient drainage, if less timidity had existed, as to the necessary amount of slope, or rise to be given to the bed of rivers. This has generally been presumed to require from 4 inches to 6 inches per mile, whereas the main channel, if properly proportioned to the area of the district to be drained, need scarcely have had any slope given to its bed, on its original construction, as whatever slope may really be necessary, will soon be provided

for, by nature, in the subsequent lowering of the outfall. The outward progress of the floods, or of the drainage, may be safely intrusted to the impulsion of the natural head of water coming from the inland district. With an enlarged view of the subject, it cannot be considered, that the navigations of the Ouse, the Nene, the Welland and the Witham are adequate, in their present state, to the vast extent of land for the drainage of which they constitute the respective outlets. It is, however, a subject of national importance, and well worthy the consideration of the Legislature, whether, an efficient system should not be immediately adopted, which should have the effect of concentrating the useful effect of the backwater upon one, or two capacious and deep channels, alike beneficial to the navigation and to the drainage.

Mr. R. Stephenson, M.P., V.P., said the Paper recapitulated, as general principles, a series of accepted truisms; but some of the conclusions, deduced from the reasonings, were not quite in accordance with his experience. It was somewhat difficult to collect the precise views of the Author, and Mr. Stephenson would regret making any observations, calling in question those views, without being better informed on some apparent inconsistencies; any remarks that might be made, must therefore be so received.

The subject of the treatment of rivers was one of great interest, and the Author had not hesitated to state his views boldly and generally; he must not, however, take it for granted, that the method which proved successful in one locality, would prove equally so, in another place, and under another class of circumstances. An Engineer having only obtained experience in a particular sphere of practice, and drawn his conclusions from the facts there observed, would soon find, on extending his field of observations, and comparing the new series with his former views, how necessary it would be to modify his previous opinions. In the course of a lengthened and somewhat varied practice, Mr. Stephenson had found it necessary to change his views several times, as to subjects, on which he had conceived his opinions to have been sufficiently sound.

It would appear, that Mr. Brooks had based his opinions, almost entirely, on his experience on the Tyne, or on similar rivers,

and had therefore only considered one series of circumstances; Mr. Stephenson had, from his earliest youth, been also well acquainted with the Tyne, and he thought the observations made, with respect to that river, were accurate and well adapted to its present condition; but he could not accord with the general applicability of the Author's views. The Norfolk Estuary, relative to which Mr. Stephenson had been consulted, belonged to a class of river alluded to in the Paper; it was a work of magnitude, to be executed under peculiar circumstances, demanding careful consideration and close observation, before deciding on the general plan, and the mode of executing the works. Various opinions had been expressed as to it, and the propriety of its being undertaken had been questioned, by parties who were called upon to advise and to exercise considerable authority; in spite however of these adverse opinions, having confidence in the general soundness of the plans, and being supported by the judgment of Sir William Cubitt, he had not hesitated to advise the interested parties to proceed with the undertaking, and he felt sure of its ultimate success.

Captain Coddington, R.E., said, if, as stated in the Paper, the filling up of the space, or interval between the groynes, was only a question of time, then the general improvement of the river was also merely a question of time, and it would naturally be asked, why not build full-tide walls immediately, instead of losing time in the construction of groynes, the line of whose points would, eventually, describe that of the side of the channel.

Mr. J. Murray gathered from the Paper, that it was proposed, by the construction of groynes and the consequent filling up between them, to restrict the channel and thus to abstract a certain quantity of tidal water. These means would certainly deepen the channel and increase the velocity of the stream, and so far the system was good, as a trial, having chiefly for object to determine, experimentally, what should be the actual content of the channel, requisite for the drainage of the district. The chief disadvantage consisted in the inequalities frequently induced in the channel, by the scooping out, or deepening of the bed, opposite the end of each groyne. This effect was avoided, where training walls were put down; but on the other hand, when they were adopted without previous trials, there was the

disadvantage of the uncertainty, as to the sectional area of channel required. This had been severely felt in the Clyde, and it was understood to be now proposed, to remove the training wall, from nearly the whole length of one side of that river, and to set it back, in order to increase the width of the channel. It had, also, been proposed, to pile in front of the new shore, where it was restricted, in order to prevent the dikes from being undermined by the current.

The abstraction of tidal water was a question of great difficulty, which did not appear susceptible of being treated by any general rule; each river must be considered and treated separately, giving a section, capable of carrying away extraordinary, as well as ordinary freshes of drainage, and this want was now being felt severely, in some localities, where, in consequence of extensive surface and subsoil drainage, the flow of water to the river was larger and more immediate, than formerly.

After training the channel, the outfall must have careful attention, in order to give the proper velocity to the water, at its junction with the sea, so as not to form a delta, or a bar.

Mr. T. E. Blackwell was not prepared to admit the classification of rivers, given in the Paper; he thought, that scarcely any two rivers would be found to coincide, beyond their broad features. Nor could he agree with the deductions, drawn from the statement of certain conditions. Take, for instance, the Severn and the Avon: according to the Author's views, there should be a bar formed, at the mouth of the latter river, in consequence of the action of the Severn upon it; whereas there was a clear channel and no tendency to silt up.

Such quick-falling rivers as the Wye and some streams in South Devon, must also be excluded from the attempted classification; there were many others, also, whose mode of management would be affected, by a variety of local circumstances, and by the character of the floods and freshets, all which must be specially investigated.

In the treatment of rivers, Engineers must, like other professional practitioners, be guided by 'symptoms,' and any attempt to apply general laws, was dangerous, and must result in the usual failure, of relying entirely on either theory, or practice; in fact there was no royal road to Engineering, although modern 'blue books,' full of general rules and deductions, were

continually published; but which, if taken without the assistance of good judgment, and a careful consideration of each case, must prove mere delusions.

Captain Hood, R.N., directed attention to the harbour of Newhaven, formed by the outfall of the river Ouse. He was well acquainted with the history of the port, as for some years he had the command of a frigate stationed there, and had always taken an active interest in the progress of the various improvements, and more especially of the present works, which had been, in a great measure, designed and executed by Mr. Stevens, the harbour-master, under the sanction of Mr. Walker.[1] The entrance was formerly very bad, and under

[1] Yarranton, in 1677, described the advantages to be anticipated from improving the harbour of Newhaven, by the construction of a western pier, and establishing the means of flushing the harbour, by the waters of the Ouse.

Collins, in his report in 1698, described it as "another small bar place;" "fit only for small vessels;" and showed how the ancient outlet had been blocked up by the shingle. Dummer's map, of 1698, showed, that the waters had forced a way out, nearly in the direction of the old river. In Horsfield's account, the decayed haven of Seaford is mentioned, as showing that the shingle had ruined it, in the time of Queen Elizabeth. Smeaton, in his report on the drainage of the Lewes Laughton Level, in 1768, described the hindrances to that work, arising from the accumulation of shingle, at the entrance of Newhaven harbour. Mr. Rennie in 1810; Mr. Jessop in 1819, 1821, and 1825; Mr. Whidbey in 1823; Mr. Cubitt in 1831, 1833, and 1835; Mr. Ellman in 1832; and Mr. Walker in 1843 and 1846—gave very ample information, as to the ancient changes of the coast and of the state of the river, and recommended various remedies for the evils complained of.

The Report of the Commissioners on the Harbours of the South Eastern Coasts in 1840, and the evidence taken by the Commissioners, upon the subject of Harbours of Refuge in 1844, gave good accounts of the then state of the harbour and the river, and enumerated many projects for improving their condition.

Mr. Walker in his First Report, March 1843, addressed to the Commissioners of Newhaven Harbour, says, "I know no harbour exposed to the sea, which, judging from the statements and accounts I have received, has been improved so much and at so little expense as Newhaven. Its natural facilities have assisted the efforts and management of the Commissioners and of their zealous harbour-master."—"During the last twenty-three years, the harbour and its entrance have deepened 7 to 8 feet."—"No harbour upon the south-east coast, as low as Portsmouth, has so good a natural backwater, or is more capable of still further improvement."—He then examines the previous works, and their effects, and recommends others, particularly the extension of the western pier, and the construction of several groynes; quoting the opinions of Mr. Stevens, based on his practical experience.

Mr. Walker's Second Report, June 20th, 1846, gives a very interesting account of the locality, alluding to its importance in a national and mer-

certain circumstances dangerous, but now, by an extension of the western pier, and the judicious construction of groynes and other works, the course of the shingle had been so directed as to be innocuous,—the depth of water was increased, so that vessels could lie in safety alongside the western pier,—the bar was diminished,—the run of the sea was subdued,—and the width of the harbour's mouth being extended to 100 feet, there was a corresponding increased facility of entrance. It was understood, that this amelioration of the state of the port was almost entirely, if not quite, due to the skill and perseverance of Mr. Stevens, who, without any previous knowledge of engineering, had learned, from careful observation of the operations of nature, how to utilize the action of the river and the tides, and by suiting the constructions to aid these natural actions, had been, at length, successful, without the aid of any Parliamentary grant, or of any other funds, than those arising from the moderate dues on the tonnage entering the Port, levied under the authority of an ancient local Act.

Captain Hood had, in his evidence, advocated the construction of more extensive works, as he considered the locality to be of great importance as a harbour, both in peace and in war.

Mr. Hawksley thought the Author had omitted the important case of an estuary, maintained by the flux and reflux of the tide, almost without the aid of upland water: this would form another category, and such cases required special treatment, in providing an entrance, of such a sectional area, as to admit the

---

cantile point of view, and offering suggestions for the improvement of the port below the bridge. The advantages offered by it, for the site of a harbour of refuge, are examined. It is described as decidedly the best harbour between Portsmouth and the Downs. The works already executed by Mr. Stevens are described, and the following credit is given to him for his skill and exertions. "I know of no harbour which has been so much improved at a small expense as Newhaven; the principal instruments being the powerful backwater, and the well-directed zeal and attention of Mr. Stevens, during the eighteen years he has been the harbour-master."

A statement is given, of the comparative condition of the port from 1767, when Smeaton reported on it, to the present time; and after showing the excellent effect produced by a groyne, in arresting the travel of the shingle, and demonstrating the general capability of the port, the Report concludes, by giving the detail and estimate for certain works, proposed by Mr. Walker, and which, if executed, would appear calculated to be of great benefit to a coast notoriously wanting in good harbours.—Editor.

necessary quantity of tidal water, without causing too great a velocity, either at the ebb, or the flow, and not to have too great a scour from the expanded inland lake, presuming such a form to be taken, as in the Mersey. The general action, in such a case, was that the moderate scour of the ebb tide kept the entrance open; but in cases such as that of the harbour of Welland, where such a lake, or pouch of water did not exist, and the upland water was inconsiderable, the bed of the river was liable to rise, during the summer months, and great inconvenience resulted. This effect would be prevented by an inland expanse of water; and if that could not be procured, training the river might, to a certain extent, produce the same effect.

Mr. J. Scott Russell corroborated the statement, as to the success of the works at Newhaven, and the skill and perseverance exhibited by Mr. Stevens; that gentleman appeared to have carefully observed the action of the river, and by judicious training, or humouring, having got it into a good condition to act upon the harbour, his operations were continued, by establishing a beach trap, which had been eminently useful, and by building groynes, which had subdued the dangerous wash of the sea; the extension of the piers and the widening of the harbour mouth should naturally follow, as soon as the general conditions of the port were such as to admit of those improvements.

It must be evident, that no general rule could be followed; each case must be treated according to its individual conditions, and those would differ in all rivers.

Such cases as treating a river by groynes at right angles with the channel, or by training walls parallel to the banks, might be discussed as abstract questions. There were two instances which might be quoted;—the Clyde and the Dee. On the former, groynes had been used and were generally abandoned in favour of training walls; on the latter, groynes were still adhered to, stretching in some cases nearly half across the river; at the extremities, there were deep holes, and between them large banks were accumulated; these underwent considerable changes at every 'fresh,' and the navigation became intricate and dangerous, demanding constant attention on the part of the pilots. It was certain that the system had not answered in that river;—no regular warping had taken place,

but on the contrary, degradation of the shores occurred, necessitating very considerable expenditure to prevent further destruction of the banks. It appeared evident, that if a sufficient quantity of water descended the river, to maintain an uniform depth, the best treatment would have been by training walls, determining the sectional area of the channel, as in the Clyde, where they were stated to have produced excellent effects.

Under certain circumstances there was a manifest disadvantage in the wide intervals between the groynes, and in general it would be found, that the parallel walls induced a more regular bed and more uniform mean depth of water; although a greater mean depth might be obtained by groynes, until the spaces between them began to fill up; when the body of water flowing up would be diminished; but the scour of the efflux would produce a larger sectional area, and then the largest body of water would be sent up, at the least velocity, between the parallel banks, as between the training walls.

It was important to remember, that the width of water surface, at the top of high water, was not so efficient in sending up a large body of water, as the mean depth of the channel. The Thames, in spite of its tortuous course, was a good river, chiefly on account of its depth; and the channel being confined between parallel walls, or banks, enabled the tide to flow upwards advantageously, whilst, on the ebb, the water was detained in the various reaches, greatly to the advantage of the navigation.

Mr. Hawkshaw thought one essential point had been somewhat lightly passed over in the Paper; it was the effect actually produced by the pouch in a tidal river. The Author stated, that he had used both groynes and parallel walls, being guided by practice and observation in their application, but no particular river had been described, therefore it was still an open question as to the ultimate result. Now taking the case of the Mersey, which had the configuration in question, it would appear, that the only advantage of the pouch was the capacity it afforded, for retaining a quantity of tidal water, to produce a scouring action; now it was open to doubt, whether the same kind of action would not be produced, by restricting the channel between parallel walls, without the danger of a deposit of sand,

or of silt in the pouch, to which there was always a certain liability. In some cases, accretion in the pouch was only a question of time, and it might be safer to restrict the space at once and thus keep the channel open. He perfectly agreed, that no general law could be laid down for the treatment of rivers; each case must be separately considered, and be dealt with, only after careful examination, extending over some time.

Captain ROWLAND said the effect of contracting the channel of the river Mersey through the pouch, or bay of the Sloyne, would be to render the stream of the river too rapid for the anchorage of vessels in it. What other effect might be produced by parallel walls, it was difficult to predict; but in the Thames, the removal of the shoals and embanking the shores, had been extremely beneficial to the navigation, as a deeper and more uniform channel had been formed, by the run of the tidal waters.

He had observed, that shoals were formed on the point of land, opposite to wherever there was a bay in the winding of the river, and also in those parts, where the tide, after passing through a narrow channel, suddenly entered a greater expanse of water-way; if groynes were constructed in such positions, so as to contract the water-way, a deposit would take place, and the tidal stream would be directed in a proper course, by which the shoals would be removed, and the bed of the channel would soon become much deeper. The general deepening of the channel had been assisted by the removal of the ledges of hard conglomerate formation, like the shoal called the 'Blackwall rock,' thus causing a more uniform velocity in the stream, on the ebbing and flowing tides, as well as giving an increased velocity of tidal water, to the upward navigation. There was little doubt, that by the formation of parallel walls, or embankments, greater uniformity of current, with an increased depth of channel would be given, and to this subject the attention of the corporation of London had, for some time, been directed, and under the advice of able Engineers, and other experienced persons, they had already expended some considerable sums on the general improvement of the Thames and its banks.

The sinuosity of the course of the Thames was advantageous to the navigation, by arresting the extreme velocity of the tide, which, for this special purpose, and for the secure anchorage of

vessels in it, should not exceed four miles per hour, yet invariably where the tide rounded a point, a shoal was formed. Although the system pursued had been successful in the Thames, it must not be presumed, that the same could be adopted in all other rivers; the method pursued must be specially adapted to the local circumstances of the stream and the geological nature of the bed; in fact, no general laws could be laid down for universal adoption.

Captain W. S. Moorsom thought, that the use of permanent groynes might be very prejudicial to the ultimate condition of a river, as the scooping out at the point was evidently objectionable, and contrary to the accepted practice, of rendering the bed as regular and the mean depth as uniform as possible. Groynes might be useful as an index for ultimately constructing parallel walls, leaving such a width of channel as was requisite for the navigation.

Mr. Locke, M.P., V.P., said the result of the discussion evidently demonstrated the impossibility of generalizing in the treatment of rivers, and that, as in all other engineering cases, however the results of previous practice might be appealed to, the only safe course was to consider each individual case on its own proper merits.

The Dee and the Mersey were so different in their characteristics, that the same rules could not, under any circumstances, apply to both rivers. The Clyde also differed from both those rivers, and there, after a vast diversity of treatment, extending over a long period of years, it was urged, that the parallel walls were too close together;—that the channel was too much restricted, and that the original object of carrying the tide up to Glasgow, so as on the ebb to scour the bar, was not attained; but that the main body of tidal water ebbed at too early a period, to be useful in deepening the mouth of the channel.

Now the Mersey, which was treated in a totally different manner, did receive great assistance from the body of tidal water stored in the Sloyne pouch, and which ebbed with a rapid scour, tending materially to keep open the intricate channels at the mouth of the river. Still no just comparison could be made between the Clyde and the Mersey. Their characteristics possessed no similarity, and in the main feature,—the position of the

port,—there was a very material difference, as Glasgow was high up the Clyde, whereas Liverpool was situated almost at the mouth of the Mersey, and had a large body of tidal water above it, always operating to keep open the channel at the port. Each case must, therefore, rest on its own merits, and no general rules could be made applicable to all cases.

Mr. W. Radford could not agree with the views of the Author, as to the longitudinal section of the tidal flow in a river, resembling a wedge. He had never found the bed of a river full throughout, at high water, at any one point; the fact of difference of time, between high water at the mouth and at a distance of twenty-five miles up the river, demonstrated this position.

Mr. Brooks would not pretend to reply, at length, to the objections raised against the arguments contained in his Paper, which, however, he thought had scarcely been thoroughly understood by the several speakers. He must disclaim any intention of dogmatically reducing engineering to general rules, to be applied without practical skill and long experience. He admitted, that every river must be considered and treated, according to its own particular characteristics, and he had only attempted to lay down a general classification, as a basis for the individual study of each special case.

As to the groynes, he thought the sooner the intervals between them were filled up, the better would be the general effect, as the scooping out opposite the ends ceased, as soon as a certain amount of parallelism of the banks was established. Mr. Rennie, in his report on the Clyde in 1807, stated, that the section of the bed showed the depth, opposite the ends of Goulburn's groynes, to be only 12 inches more than at the intervals between them.

In the Dee, there were positions where the channel was too much restricted, and as a natural effect, the stream washed over the groynes, preventing any accretion and even scooping out the banks. It was evident, that in this, as in other instances, groynes could not be advocated as the best method of permanently ameliorating the channel, but they were valuable as a means of preparation for good training by parallel walls, or embankments, when the correct sectional area should have been practically demonstrated.

Referring succinctly to a few well-known rivers, he would mention the Avon, below Bristol, as a stream coming within the category of a good river, whose rise was due to the longitudinal section of the bed, and to the great flow of the Severn across its mouth, as well as that of the Wye.

The Severn was a rapidly rising-river, with curious tidal phenomena, due to the natural configuration of the channel. Above Beachly it expanded greatly and the velocity of the tidal flow decreased, whilst a body of water was held up, which was of great utility in scouring and keeping open the mouth.

In the Mersey, from the form of the channel, the loss of tidal range was as much as 16½ feet at Runcorn.

The bed of the Humber had very little rise, but there was a large body of water and no bar was formed; whilst the Rhyl had a very rapid rise and a bar was constantly forming.

The Ouse, at Newhaven, was an example of a river having a bar, due to the reduction of the rise of the tidal column between the piers; it was there about 3 feet less than at sea, and the diminished velocity was a serious defect.

He must contend, that, in many cases, the opposition to the entrance of the flood tide, had produced great injury; in fact, the first quarter of the flood, instead of running unrestricted up the channel, was reduced almost to a mere swell, which, with the confliction of tides, tended to form bars, in all streams where the rise of the bed was rapid.

On the other hand, wherever the inclination of the bed was small, and the channel was unrestricted, the flow and ebb were effective in preserving an adequate mean depth, and there was not any tendency to form bars.

Mr. Rendel, *President*, said it was important, when considering questions of this kind, to examine attentively the most minute features of the coast, and particularly those near the outfall of the river, as also the direction, and duration of the tidal and river currents, as compared with the form and direction of the coast, on either side of the outfall. He knew of no form of outfall, which demanded so much care, on the part of the Engineer, in designing works for the improvement of the mouths of estuaries, or rivers, as that where one headland considerably overlapped the other; as, for instance, in the River Tyne, and more especially where, as in that case,

the flood stream was made to overrun the entrance to the harbour, by reason of the difference in the projection of the headlands. The omission of due attention, to any one of these and to numerous other technical points, might be fatal to the success of any works.

The treatment of the upper reach of a river must depend on so many considerations, as to defy the application of any general rules.

The President directed attention to the work recently published by Mr. E. K. Calver, R.N.,[1] a copy of which he had transmitted to the Institution. As also to three letters to the Tyne Improvement Commissioners.[2] These, although of a controversial character, contained practical illustrations of the effect of different systems of training, calculated to be essentially useful.

There were many members and habitual visitors, who were so thoroughly conversant with the subject of river training, that it would be easy for them to give practical examples of the effect of the various modes of treatment of well-known rivers, and he hoped, that in the course of the present, or the next session, such a Paper would be brought forward. The subject was of such importance, demanding the exertion of all the theoretical knowledge and practical skill of Engineers, that a more valuable class of Paper could scarcely be selected for the consideration of the members.

November 16, 1852.

JAMES MEADOWS RENDEL, President, in the Chair.

The discussion upon the Paper No. 879, "On the Improvement of Tidal Navigations and Drainages," by Mr. W. A. Brooks, being renewed, was extended to such a length as to preclude the reading of any communication.

---

[1] Vide "The Conservation and Improvement of Tidal Rivers," by E. K. Calver, R.N. 8vo, London, 1853; Weale.

[2] Vide "A Letter to the Tyne Improvement Commissioners," by E. K. Calver, R.N., with Replies by their Engineer, W. A. Brooks, and by T. J. Taylor, C.E. Tract, 8vo, Newcastle, 1852; Hernaman.

Forbes' Ship Life-Boats.

After the meeting, Mr. Doull, jun., exhibited a model of, and described a system, proposed by Mr. James Forbes, for lowering and raising ships' boats, and also the construction of a Cylindrical Ship Life-Boat, which latter, it was contended, approached nearer, than any other construction, the combination of the qualities considered requisite for a boat of that class.

The Cylindrical Life-Boat was 30 feet long, 8 feet wide, and 2 feet deep, when opened out; it would carry, with ease, sixty persons, with provisions for a week, in the air-tight seats,—could not be upset,—or swamped,—could be pulled either end foremost,—was steered with an oar,—had extra buoyancy in water-tight compartments, and was so constructed, that a hole might be knocked into one, or more divisions, without danger to the whole, and was fully stowed with masts, sails, oars, and everything complete, so as to be always ready for use, on any sudden emergency. When folded up, it was perfectly cylindrical, and on reaching the water it opened out, and could, in a minute, be made a stiff boat; and the dimensions could be modified to suit any vessel. The cylindrical form, and its lightness of construction, would enable a boat of this sort to be put over the bulwarks by six men, without tackle of any kind, and by merely cutting a lashing when in the water, it would fall open, when all the stores, &c., would be found made fast within, and ready for use.

The apparatus for lowering boats consisted of two davits, with tubular stems, down which the ropes passed, through sockets in the bulwarks, to a drum on which they were coiled, so as to be easily wound up by a wheel and pinion, with the exercise of very little power, and in lowering, a friction-break could be used with great advantage. By this means the boat would swing out very easily, as the davits could turn entirely round, and it would be nearly impossible that a boat could be swamped, in the heaviest sea, or under circumstances of the greatest difficulty.

November 23, 1852.

JAMES MEADOWS RENDEL, President, in the Chair.

No. 880. "On the Drainage of Towns." By ROBERT RAWLINSON, Assoc. Inst. C. E.[1]

THE Drainage[2] of Towns is so comprehensive a subject, that its full and complete treatment, within the limit of a communication to be read at one evening meeting, would be a useless attempt; the object of the present paper, therefore, is restricted to furnishing topics for a discussion, during the course of which, it may be anticipated, that the merits, and demerits, of the different systems of sewerage, will be fully developed and freely canvassed.

Town drainage may be considered historically, politically and socially. The historical portion of the question need not be entered into, further, than to say, that remains of what appear to have been drains are found in the long-buried cities of Syria, and the sewers of ancient Rome partake of the fame of "The Eternal City;" indeed the Cloaca Maxima is asserted, by some authors, to have been the work of a people older than Romulus. Livy, however, gives the reign of Tarquinius Superbus, as the date of its formation.

Politically—the question of the best system of town sewerage and of house drainage, is very urgent, and at no period has it ever been of greater importance, than at the present time. It may be clearly shown, that the progress, if not the permanence of civilization is dependent upon a correct appreciation of its merits; as the healthy existence of town populations must ever be influenced by their sanitary condition. Misery, pauperism, vice and crime find a forcing-bed in the unsewered parts of towns, and amidst the foul air of undrained houses.

---

[1] The discussion upon this Paper extended over portions of four evenings, but an abstract of the whole is given consecutively.

[2] Drainage and sewerage, as connected with towns, are treated in this paper as synonymous. Sewerage is, probably, the proper term, as applied to towns, and drainage to the country.

This may not be self-evident, on a cursory consideration, but facts and figures, which will not admit of contradiction, can be brought in aid of the assertion.

The tendency of modern civilization has been to congregate the human race in masses, and in Great Britain, the extension of towns is unprecedented. In 1841 the population in one hundred and seventeen districts, comprising the chief towns was 6,612,958 souls. In 1851 in the same districts the number was 7,795,882, being an increase of 1,182,924 in ten years. When it is remembered, that the greater portion of the area, thus populated, is comparatively low and flat; such as in seaports, on the banks of inland rivers, or in valleys intercepted by canals, it is not surprising, that this crowding should produce disease, as is proved by the almost constant presence of fever, and a recurrence of the more deadly cholera. It is quite true, that disease, in some terrible form, or other, has ever been associated with man, when thickly congregated, whether in cities, in towns, or in armies—but it may also be shown, that much of this disease has been of that class, which, by due precaution, might have been averted. A full elucidation of this portion of the subject, belongs rather to the medical department, than to that of Engineering; it may, however, be stated, that the averages of mortality, though much higher in town, than in country districts, do not reveal the worst feature of the case, as the annual number of deaths, in the most unhealthy parts of a town, are frequently as ten to one, compared with the better parts of the same town. That is, if ten out of each thousand die annually, in one district of a town, one hundred out of each thousand perish, in another quarter of the same place—so that a statement, of any given average of deaths, per thousand, would be liable to mislead. The average number of deaths, in English towns, ranges from twenty to thirty per thousand. In country districts, the average does not exceed seventeen, or eighteen, per thousand—and amongst the well-regulated classes, only about ten to fifteen deaths, per thousand, occur annually. In the convict prison, on the Isle of Portland, the annual average of deaths is only about five per thousand. There are, however, in that establishment, neither infants, nor very old people, to swell the mortality.

This portion of the subject may be closed, by a quotation from a valuable Report, on Cholera in England, recently issued by the Registrar-General, in which he says:—" A large portion of the next generation of Englishmen will be born in town-districts, some of which are high and healthy, while others low, insalubrious, subject to inundations and to the incursions of cholera, present many of the circumstances in which a degradation of race is inevitable. In the dense districts of Lancashire, where the health of parents is depressed, and the circumstances are often so prejudicial to their offspring, that, of the coming generation five, instead of two, of every ten born, are destroyed in the first five years of life, and the survivors, with a few happy exceptions, are left with shattered, feeble, febrile and disorganized frames—degeneration is as inevitable, as the degeneration of horses, oxen, and sheep, in circumstances equally unfavourable." The might of a nation consists in the health and strength of the people—therefore the supremacy of a country is, in a degree, dependent upon its general sanitary condition.

It is, however, to the social effect of town drainage, that the attention of Civil Engineers will be most naturally directed, as under that head, the leading principles of actual practice, and those modifications which have been proposed for adoption, must be brought forward and discussed. So much has been recently said and written upon town drainage, that it will be quite impossible to strike out either a new, or an independent course, nor is it advisable to do so, as to study precedent,—to learn from experience,—and to correct from practice, are the chief duties of an Engineer.

The much-disputed question of, " in what good town drainage consists," can only be answered by the exhibition of actual works, which do fully answer their intended purpose. The forms and dimensions of sewers, the materials of which they may be constructed, and the depths below the surface at which they should be laid, admit of some moderate difference of opinion; but certainly not to the extent, now permitted in practice. In one position a brick sewer 5 feet high by 3 feet wide will be constructed, at about £2 10*s.* per lineal yard, whilst in a similar situation, there will be laid down an earthenware tube, 1 foot 3 inches in diameter, at an expense of 8*s.* or

10*s*. per lineal yard. There must be something positively wrong in such discrepancy of practice as this, and the sooner the truth is discovered and proclaimed, the better will it be for all parties. If that man is a benefactor to his race, who makes two blades of wheat grow, where one only grew before, he is likewise so, in a degree, who constructs two lineal yards of effective sewer, for the price that has before been expended upon one yard; if the cheaper sewer performs its functions more, or even as, perfectly, then is the achievement so much the more worthy; but if it does not perform so well, then the innovation becomes an injury.

It has been asserted, that no street sewer ought to be less than will allow a man, or a boy to pass along it. The Legislature has passed an Act to prevent boys being sent up chimneys, and, better arrangements being made for providing water for flushing, it may, some day, be inclined to pass an Act to prevent men from entering sewers. The latter will be more humane than the former; as, it is asserted, that more lives have been destroyed in foul sewers, than ever were lost in crooked chimneys.

In town drainage there are three primary considerations:—

1st. The line for the outlet sewer, or sewers, if more than one such be necessary.

2nd. The dimensions of these outlet sewers, and their form.

3rd. The materials of which sewers may best be made.

The position of the outlet, or outlets will in some measure be governed by natural conditions. They must be in such a relative position as shall least endanger health; and wherever it is practicable, only one outlet should be formed, as the refuse will then be concentrated, either for natural removal, or for agricultural use.

The size of outlet-sewers must be fixed by the number of houses to be drained, and the extent of the area upon which they stand.

The site to be drained may consist of flat alluvial land, impervious mud, or pervious gravel shingle; or the town may stand on the banks of a tidal river, the surface being very little above the high-water line,—or it may be actually below the

level of high-water of spring tides. Then there are inland cities and towns, through a part of which, flow rivers liable to excessive land floods, and the waters may be impeded by locks, for the purposes of navigation, and by weirs, for mills.

The site to be drained may be partially a flat plain and partially rising land inland, showing a tolerably straight front, or being convex towards the plain. The land may rise on both sides, as in a creek, or bay—or may consist of several such creeks, with natural water-courses passing through each, bringing down the surface-waters of suburban areas, much larger than the town itself—these, and other innumerable combinations, which need not be specified, are all questions, for the treatment of which no fixed rules can be given ; each individual case will demand special study, and must have local knowledge and care.

That the question may however be discussed, certain rules relative to town sewers will be assumed, which may, or may not be established.

1. They cannot receive the excessive flood-water, even of the urban portion of the site.
2. They ought not to be combined with the natural water-courses, which drain large areas of suburban land previous to entering the urban portion.
3. They should be adapted, exclusively, for removing all the liquid and soil refuse from the houses, in such a manner as to cause the least possible nuisance to the inhabitants.

Where the site of a town is a plain, only little elevated above the tidal water-line, the delivery of the refuse from the sewers, must either be by pumping, to render it constant, or it must be intermittent, and, therefore, leaving the refuse, for a time, stagnant in its channels of conveyance. Sewers and drains are frequently required, in situations where high tides, land floods, or both combined, cover to a considerable depth the surface beneath which such sewers must be laid ; or, if the area is embanked, the waters rise above the level of the land and the outlet. These circumstances frequently serve as excuses for not attempting the formation of any sewers, or drains, and most certainly it is much safer to the inhabitants, that there should be no sewers, than that there should be

sewers of deposit. That towns so situated may, however, be perfectly, and even economically drained, is proved by the condition of Holland, where the land is almost all below the level of the sea, and yet it is the most densely populated country in Europe. In England, great portions of Lincolnshire, Cambridgeshire and other counties, with large areas of agricultural land only worth from one hundred to two hundred pounds per acre, are drained either by intermittent action, or to a great extent by pumping machines, designed by and erected under the direction of Members of this Institution.

That which is done profitably for agricultural land, may assuredly be carried out for town sites, where the intrinsic value of the land and of the property placed upon it (exclusive of the importance of preserving human life) is, in many instances, as one hundred to one, or even more.

Inferentially it may therefore be stated, that town sites may be profitably drained by pumping, independently of any commercial value attached to the sewage refuse.

Where a town site is partially a plain and partially rising ground, sloping towards the level, or low portion, the formation of intercepting lines of sewer, to receive the contents of the sewers and drains of the higher portion, and to prevent their falling into the lower level, will save much pumping.

The sewers formed in level, or low districts should be of minimum dimensions,—they should be laid as near the surface as is consistent with their safety, and should be constructed of a material capable of bearing external pressure, without crushing, and internal pressure, without leaking, or bursting. If sewers, connected with a pumping establishment, are much larger than corresponds with the lifting power employed, the current through them will be sluggish, and deposit will take place. It will be evident that such sewers should not be unnecessarily deep, in order that the artificial lift should be as little as possible; and they should be capable of resisting hydraulic pressure, as they will be liable to be filled above the crown, either through an extraordinary rise of tide, or through heavy land floods. This latter consideration involves the question of sluices and valves which however need not be entered upon in this Paper.

Another reason, why sewers in flat districts, liable to surface flooding, should be of minimum dimensions, is that maximum

volumes of water, in such places, cannot be provided for in sewers. The River Eden, at Carlisle, rises about 20 feet, and the River Ouse, at York, rises about 18 feet, above summer level, laying under water, areas of many miles square. Large sewers, in such districts, would give no relief, at such times, and in dry weather they would be a nuisance.

The assertion that, "Town sewers should not receive suburban waters, or excessive suburban rain-fall," requires some explanation. The area drained by natural streams may be much larger than the urban area,—and, therefore, any arched channel, or sewer, to convey away, safely, the flood-waters of such a district, must be in proportion to such area. The cost, of course, being in proportion to the sectional dimensions of the tunnel, or sewer formed. Another consideration, which ought, also, to have great weight, is, that the flow of flood-waters is intermittent, whilst the flow of sewer-waters should be constant, —that is, the sewers should be as much as possible self-cleansing, by the daily action of the fluids passing through them. This cannot be the case, if a small body of water is spread out over a wide bottom, or invert. There must, in such a case, be a deposit, which will be increased by such obstructions, as stones, sticks, road-sand, gravel, etc., which will be carried from the open water-courses into all sewers, or tunnels, receiving the flood-waters of a suburban district, because the channels leading to the sewer, and the end of the sewer itself must be open. The stagnation of sewage refuse, in such places, will also be greatest, during the driest period of the year, when the evaporation will be most injurious.

Several reasons may be given for the assertion, that "Sewers, other than main outlets under particular circumstances, should not be calculated to contain the flood-water of an excessive rain-fall,"—though one only ought to suffice, namely, that the waters of an excessive rain-fall cannot be passed through any ordinary gully-grates, into the sewers. In Birmingham, on the evening of Sunday the 6th July, 1845, there fell 1·945 inch of rain, in little more than half an hour. This was equivalent to 9·091 gallons upon each square yard of surface, or 44,000 gallons, to each statute acre.[1] This is, no doubt,

[1] *Vide* Report to the General Board of Health on the Town of Birmingham. By R. Rawlinson, May 1849, Page 9.

such a flood as is seldom met with, but equal volumes of rain have fallen in the metropolis, and in other places in England. Those who have any given area to drain, for town purposes, taking these figures as multipliers will ascertain about the maximum, if they premise, that sewers ought to be of sufficient capacity to receive the storm-waters, and to retain, or pass them off below the level of the cellars. In many cases the storm-waters will pass over the surface, after the formation of sewers, just as they flowed away before the construction of any artificial conduits.

The dimensions of sewers ought, in some measure, to fix their depth below the surface, as there ought to be a fall of not less than one in sixty, from the deepest house, or cellar-drain, to the highest water-line, to which a sewer can safely be allowed to be filled.

In arranging a system of town drainage, an Engineer must consider the following questions:—

1. How has the flood-water hitherto passed away, seeing that there never has been such a work as a sewer in the district?
2. What has been done on the surface, in the formation of quays, roads, or streets, or in any other way to impede the free escape of the surface-water?
3. What are the effects experienced during land-floods?
4. Is it practicable to construct sewers, large enough to pass the whole volume of a maximum rain-fall, at such a level, as shall not inundate the cellars with back-water?
5. What additional length of outlet will be involved, to secure the fall required for large and deeply-laid sewers?

These are all questions of the utmost importance, involving economy and efficiency; but there are other minor questions, which an Engineer should settle, before finally deciding on a system of town drainage.

There are sites upon which houses ought never to have been built, and cellars have been dug, where the natural outlets, upon the surface, have been contracted, or destroyed, instead of being preserved and improved. In such cases an Engineer should

constitute himself Nature's journeyman, and by carefully observing the natural features of the locality, and using them as much as possible, attain his end more readily than by attempting any forcible control.

There are cases in which it is the province of an Engineer, in some degree to oppose Nature, but this must ever be a costly and dangerous undertaking, and nothing short of actual necessity will justify the attempt. The greatest men in the profession have shown, by their works, that they never undertook an opposition course, when they could accomplish their purpose in an easier manner.

In town drainage, Nature must first be consulted, and effective assistance may then be given to her operations at the least cost. Where there has never been a sewer, it may not be considered necessary to construct one 5 feet deep by 3 feet wide, at a depth of some 15 feet, or 20 feet below the surface of the street, to the great danger of all the adjoining property, and, in many instances, to the certain destruction of the natural outlet.

If it shall be decided, that town sewers are not to convey away the drainage waters of suburban districts, and if it shall, further, be granted, that they cannot be made of sufficient capacity to contain even the urban waters, during maximum rain-floods, it may naturally be asked, of what dimensions should town sewers be constructed? and this may be partially answered by considering the principal intention in constructing town sewers.

If it be for house and yard drainage, then to these they should be adapted,—and there will be reliable data from which to calculate their dimensions. The sewers and drains will be of minimum size, and will, consequently, not require either very wide, or very deep excavations to be made, and the cost of the work will also be reduced to a minimum.

It will be admitted, that many large sewers were not originally constructed to serve the purpose to which recent practice has adapted them—namely, to receive and convey away the contents of water-closets for an entire population.[1] The asser-

[1] The Cloaca Maxima was designed and used by the Romans for conveying away both fluid and solid sewage.

tion may sound strange to the dwellers in this metropolis, where the practice of water-closet drainage has prevailed for some time; but few even of the metropolitan sewers, were designed solely with reference to house-drainage. This duty has been subsequently imposed, but even now there are miles of sewers which do not receive the drainage of one-tenth of the houses in the district.

In Paris the contents of water-closets are generally excluded from the public sewers, and it is only recently, that the law has been repealed in Liverpool, forbidding the turning of water-closet refuse into the sewers. The architect of St. George's Hall was obliged to arrange for the construction of large cesspools beneath the foundations, to receive the contents of the water-closets, proposed to be erected in that building.

There are, in many towns in England, great lengths of sewers, which do not receive the adjoining house-drainage.

In discussing the best form for sewers and drains, it is necessary to consider carefully their dimensions, and the materials of which, under all local circumstances, they can most advantageously be made. The nature of the subsoil must first be well ascertained, before either the form, or the material can finally be decided upon; that is, the Engineer will frequently have to modify both the form and the material, in order to overcome some natural difficulties which could not be foreseen, but which will induce more, or less alteration, from the first design, and not unfrequently occasion even partial failure, in the works of the ablest and most watchful Engineer.

In existing sewers and drains may be found almost every sectional form, of which such constructions are capable; they are V shaped, square, oval, and circular, and also partake of every intermediate combination of these figures;—V bottoms have been defended;—flat floors, or inverts, have been advocated, and the egg shape has been insisted on, even down to drains of 4 inches in diameter. There have been as varied assertions, relative to diameters; but that question need not be discussed here, as actual works, the great test of Engineering, can alone give a practical solution to this question. Beyond all dispute, there are many miles of sewers in existence, very much too large and there may be some too small.

Rules have their use, and that man who works without rule

will seldom be right; but he who works by rule alone may also sometimes be wrong.

Rules for the diameters of sewers, and drains, to remove, not only the ordinary flow, but also the storm-water of districts, have recently been published,[1] and, as these rules are within the reach of every Member of this Institution, more need not be said relative to them, at present.

If the materials, of which sewers may be constructed, are to be subjected to local contingencies and conveniences, the sectional forms may be more definitively settled.

Sewers, having a transverse sectional width of more than 2 feet, should have a circular invert, in order that the minimum flow of water may be concentrated.

For sewers, less than 2 feet in diameter, the strongest form is the circle, whether they be constructed of pipes, tiles, or bricks. There may be an advantage in the egg shape, when sewers exceed 2 feet in diameter, but practically, that form possesses none for lesser dimensions, and should not, in practice, be adopted for small sewers, or drains.

The best material for the construction of main sewers, is a question only to be determined by practical results. Brick, stone, and cast-iron, either used singly, or variously combined, have each their partizans; recent practice has however indicated earthenware pipes as (apparently) the most economical and effective, for all sewers and drains, under ordinary circumstances, and within the capacity of the material. They have been made from 3 inches up to 30 inches in diameter; the former are too small for any drain,—the latter are too large for the material of which they are made.

It is self-evident, that theory alone cannot be followed, in determining the sectional area of house-drains; if it were, they might be reduced, in some cases, to the size of a quill, as more water will pass through such an aperture, in the course of twenty-four hours, than is used in a cottage; but drains are devoted to other uses than the mere passage of fluids through them, and their sectional dimensions must be adapted accordingly. It will probably be eventually shown, that 4 inches in

---

[1] *Vide* "Minutes of Information on Sewerage and Cleansing of the Sites of Towns;" General Board of Health Reports. 1852. Page 67.

diameter is the minimum sectional area to be given to house-drains, and that they should not be laid at a less gradient than one in sixty.

This question of size may, however, now be left to be settled by practice; discussion rarely makes converts; but facts are stubborn things, when they can be arrived at without any colouring of prejudice.

The theory of pipe-sewers has been recently much agitated, and without undue advocacy of extreme views it may be asserted, that no discovery of modern times is more fraught with benefit, if properly applied, than the use of pipe-sewers for town and house drainage. Streets have been effectively sewered, and houses efficiently drained, by earthenware pipes, where neither sewer, nor drain would have existed, if costly brick constructions had alone been available.

Earthenware-pipes cannot, however, be beneficially used, as sewers, beyond certain limits, which can only be settled by practice; temerity will lead to failure, and failure will correct theory; the Engineer who is anxious after truth will not denounce a system, because some men push it to extremes, and hence he will use the mistakes of other as his beacons.

Various forms and modes of jointing earthenware-pipe sewers have been tried; there are plain ends, or "butt-joints," rebate-joints—full-socket joints—and half-socket joints. There are also both circular and egg-shaped sections. About fifty miles of pipe-sewers are laid in Manchester, the majority of which are egg-shaped, with plain, or "butt" joints, finished with clay. These pipes range from 4 inches to 30 inches in height and are laid with the narrow side down. In twenty-five miles of main sewers, also laid with pipes, there has not been a single case of failure, and in the lateral drains, wherever a few failures occurred, their causes were easily discovered; indeed at Manchester, the pipe-sewer system may be said to have proved most successful, and in a recent report of the Town Council it is stated, "The economy effected by the use of tubular sewers is palpable, and the result will be, no doubt, a great extension of the practice of draining, and consequent improvement of the public health."

The maximum dimensions of pipe-sewers, must be governed, in some measure, by contingent circumstances. At present

15 inches, or 18 inches diameter, is the extreme size to be recommended for socket-pipes, and in laying these, great care must be taken, or through unequal bearing, the pipes will break each other at the joints.[1] Pipes with plain ends may be laid of as large dimensions as the material of which they are made will allow; care being taken to secure fair fitting and equal joints. Full-socket, or half-socket pipes, of 12 inches in diameter and under, may be used with advantage; where they are restricted to these dimensions, the pipes are much more uniform in shape, the relative strength of the material is much greater, and there is little danger of such pipes fracturing each other. The difficulty in moulding, drying and burning pipes increases, probably, as the squares of the diameters. If large pipes are moulded too thin, the finished sewer is liable to be crushed, and if they are moulded of extra strength, the wet pipe collapses by its own weight in drying.

The side-junctions, as moulded by the best makers, are a great improvement upon the direct entrance of brick-sewer branches, at right angles with the mains. A well-made pipe-junction increases the velocity of the current, by passing the sewage into the main, in the direction of the flow, and all side-junctions should have a quick descent, for the last 3, or 6 feet, before reaching the main.

Good and cheap sewers may be made with either solid, or hollow radiated bricks, having their beds in the radius line of the curve. Bricks of this description cost very little extra; they may now be moulded of such dimensions as are required; —for instance, sewers of 2 feet diameter, may be made with bricks 4½ inches on the bed; those of 2 feet 6 inches diameter, with 6 inches on the bed; and those of 3 feet diameter with 7 inches on the bed and so on upwards;—the limit being the capability of moulding the bricks with economy and of the workman handling them with facility. Hollow bricks may be used advantageously for the external ring of sewers, constructed

---

[1] In recent practice, the Author has discontinued the use of full-socket pipes, above 9 inches in diameter, and has either adopted half-sockets, or used butt-joints laid on earthenware chairs. Unequal bearing at the joints, has chiefly caused the fracture of the pipes, which has been so much complained of, and which should be specially guarded against.

of more than one brick in thickness; the horizontal perforations forming channels for the land drainage.

Sewers of radiated bricks, set in cement, are cheaper than large pipes; that is, a brick sewer of 3 feet in diameter is cheaper than one of pottery 20 inches in diameter; the capacity of the sewers being as the squares of the diameters. There is no reason why brick-sewers may not be made as smooth and as impervious to wet, as pottery pipes—either by selecting bricks of peculiar quality, or by having the surfaces prepared with asphalte. It is difficult to arrange perfect side-junctions in brick sewers, as every inlet should curve in the direction of the sewage flow; but pottery junctions may be worked into the brick sewers, or, in some cases, cast-iron inlets may be used.[1]

In a system of sewers and drains, man-holes, at intervals, will be of great service. These may be simple shafts of brick-work 2 feet 6 inches or 3 feet in diameter, carried up over the line of sewer; if placed at intervals of one, or two hundred yards apart, they enable the Engineer to examine the action of the sewers, and, should a stoppage take place, the exact spot is more readily indicated and discovered. They are especially useful at street junctions.[2]

Street gullies are generally trapped, and there is a receptacle for the heavy detritus of the roads. Here again, local contingencies will affect the application of rules. Small towns, with paved streets where there is little wear and a good fall for the sewer, need not have any elaborate gully arrangements; the surface water may pass at once into the sewer, or into a well, or receptacle for the grit, out of which a plain bent pipe passes to the sewer; which latter will be all the gully arrangement required. Gully-grates should be tolerably fine; that

[1] Since this paper was written, the Author has used stone inlets. The beds of the stones are worked to suit the radius of the brick sewer, and the inlet for the pipe drain is formed out of the solid stone. Messrs. Doulton have since made a pottery inlet, which must supersede the use of stone.

[2] In all the work done, since this Paper was prepared and read, the sewers, whether of brick, or of pipes, have been laid in straight lines, from point to point, in lengths as great as were practicable. At the change of direction, or of gradient, there is a man-hole, or hand-hole, to allow of examination, so that the light is never lost through a sewer.

is, the apertures should not exceed ¾-inch, and if there is a kerb-stone, the grate may dish towards it and be continued up the side; so that, should the surface become choked, the water will pass off by the vertical side. Large openings into pipe-sewers should not on any account be permitted.[1]

Sewers which require trapping, are either faulty in construction, or their action, in use, is imperfect. House-drains may be trapped by a plain bent pipe; mechanical traps of every kind ought to be avoided, they are a delusion and a snare; hinged traps impede the flow of sewage and do not prevent the escape of foul gases.

There should be full and free ventilation of the sewers, at all the highest and most convenient points of a town, and where any escape of foul gas will be the least nuisance. Ventilating chimneys may be of much service in flat districts of great extent, or the steam jet may be applied; but furnaces should be used with caution, as the gases of a foul sewer are liable to explosion.

In some districts cast-iron pipes may be used for sewers, with great advantage, as, for example, where there is partial flooding, by land-floods, or by tides; or, in heavy ground, in quicksands, and to cross intervening spaces, where towns stand upon alluvial shingle, within tidal influences. Externally they may be laid in clay,—internally the metal will be protected by the fatty matter of the sewage.

The question of Town Sewerage, or Drainage, has of necessity been very briefly and imperfectly treated in this paper. Each branch of the subject might be made a text, which would require an entire essay, with many diagrams for its illustration; but as the Author's principal object has been to elicit opinions in a discussion, he has merely ventured to treat generalities.

Certain rules may, however, be given for Town Drainage:—

Sewers should be below the level of cellars, and they should be adapted to the especial work they have to perform.

Rivers, brooks, and natural streams should not be made part

---

[1] A gully grate has been invented and used by the Author, which effectually traps the drain, and yet allows a direct communication with the sewer. It enables the drain, or sewer to be flushed with the full force of any water at command, as a hose-pipe can be passed direct into the drain leading to the sewer.

of a system of sewers, and the sewers themselves, in low districts, should be capable of resisting internal pressure.

Wherever it is practicable, the sewage of high districts should be intercepted, so as to preserve a free outlet at all times, for this portion of the system.

Small sewers and drains should be circular; large ones should be oval, or egg-shaped.

The longest practicable radius, should be adopted, in laying out curves on lines of large sewers, and there should be an extra fall in the curve, especially at a junction with a main sewer.

All sewers and drains should be impervious to water, and should present even and smooth surfaces; special arrangements being made for land-drainage.

The gradient, or fall of large sewers, in steep ground, should be modified; that is, the gradient should be interrupted, or, the sewer should be made of such material as will resist the tendency to rapid wearing away.

Wherever it is practicable, the outlet, or delivery of sewers should be free, and in every case there should be full and free ventilation.

Cesspools within a town, and either beneath, or attached to houses, are subversive of sewerage and drainage; indeed, no town, or city can be considered as drained, in which cesspools are permitted to exist.

Cesspools, or manure tanks, at, or near an outlet, are nevertheless admissible; care being taken, that such outlet, or delivery of the sewage refuse is not blocked, or impeded, and that there is no in-draught, or back-draught, through the sewers.

The true purpose of town sewers is the instant removal, from the vicinity of dwelling-houses and from the sites of villages, towns, and cities, of all refuse liable to decomposition, and which is capable of being conveyed in water. The more fully this is accomplished, the more perfect will be the system. Efficiency, durability, and economy should never be lost sight of, and though the drainage of towns may not, at first, appear to be an attractive occupation, yet if the works are well designed and executed, it will neither be the least noble nor the least useful pursuit of the Civil Engineer.

Mr. Rawlinson admitted, that his paper might be considered loose and discursive, but he had written it chiefly for the purpose of eliciting opinions on a question of great social importance, and he was ready, in answering the questions put to him, to afford any additional information in his power. It might be said, that there were some positions unduly assumed; if so, they would be overthrown, and the erroneous conclusions would be pointed out.

Perhaps the best method of opening the discussion was to state a few facts, in connexion with the drainage of a town, where, from local circumstances, only earthenware pipes had been used. He alluded to the town of Hitchen, where upwards of 60,000 feet of pipe sewers, from 20 inches down to 4 inches diameter, and 2 feet 6 inches long each, had been in action for four months, with perfect success; the average depth below the surface was 8 feet, and the outlet of the main sewer, which was 5000 feet in length, and only 20 inches in diameter, was laid, in part, beneath the bed of the river, at an inclination of one in eight hundred. This was designed for the sewerage of one thousand houses, of which only two hundred were at present connected, and for eleven hundred acres of urban and suburban drainage. He admitted, that some of the pipes, laid to a pumping engine, had been broken, from being laid in bad ground, but after being relaid in wooden troughs, no further fractures ensued. He was aware, that the system of pipe sewerage had been, and must be, modified in practice, to adapt it to certain localities; that in a rocky uneven bed, improperly loaded pipes would break, and if of large dimensions, they were very liable to be split longitudinally, or be fractured transversely, as it was very difficult to get them accurately made and burned, and the false bearing at the sockets caused breakage. If in the case of Hitchen, the rule laid down in Mr. Roe's tables had been followed, the outlet must have been 5 feet diameter, instead of 20 inches diameter.

No attempt had been made to divert the natural flow of the surface-water; the street gullies being connected directly with the pipe sewers. In this, as in the arrangements for all towns, an engineer must modify his practice to meet local circumstances. He was satisfied with the general results at Hitchen, and as the

earthenware pipes, supplied by Messrs. Doulton, and put together with clay joints, both of the full, and half socket forms, had supported an internal pressure of a head of 4 feet, there was not much reason to find fault.

Pipe sewers had been in use at Manchester, for seven, or eight years, and Mr. Francis had expressed his satisfaction with the result; the only difficulties had arisen from a few cases of the choking of some of the smaller-sized pipes. In that instance, where a great extent of oval pipe drains, 25 inches by 18 inches, had been laid, with success, it should be explained, that they were 2¼ to 3 inches in thickness, and were laid with great care in strong ground. The maximum size at which, even these thick pipes were preferable to brick sewers, was 30 inches by 24 inches. The smallest size made for small streets was 12 inches by 9 inches, and for foul water 6 inches by 4 inches. The largest area draining into a pipe sewer was about fifty acres.

On the authority of Mr. Harper, and quoting from a communication relative to some houses in Back King-street, Bury, he stated, that though they had formerly been in so bad a state as to be untenantable, in consequence of fever constantly raging there, they had been rendered perfectly habitable, by being drained with earthenware pipes, and that the experiment had been quite successful, as regarded the general amelioration of the district.

Mr. G. Donaldson said it was generally admitted, that partial failures had occurred in almost every locality where earthenware pipes had been used; the causes were, fracture of the pipes in unsound ground, and choking up, wherever there was not a rapid fall. Now the frequent occurrence of these fractures would render the pipe system eventually more expensive, than that of good brick sewers, and the annoyance and inconvenience to the public, from continually opening the streets to discover the stoppages and clean out the pipes, would become unbearable. Common sense and practical experience dictated the course of having good brick main sewers, and well-burnt earthen pipe drains, of sufficient diameter leading into them, from the houses. By this means such failures as had occurred at Croydon, and the accompanying annoyances and ill effects on

the health of the inhabitants, would be avoided. He had visited Croydon and satisfied himself, as to the correctness of the statement, that in several places the pipe sewers were crushed, and the workmen, in charge of the repairs, stated, that several thousand feet of the larger pipe sewers were also fractured; indeed it was difficult to say how much remained in a fit state for conveying away the sewage. In several instances he observed, that a covering of clay was put, and half-brick arches were turned over the pipes, to preserve them from the pressure of the earth; in almost all cases, the pipes were split from end to end, and the clerk of the works, on the spot, informed him, that the broken pipes were very tender and friable, when first taken up out of the trenches, but on being dried by exposure to the air the substance became hard and comparatively strong again. Now it did appear to be false economy to push, to excess, the use of a system, which, if applied with judgment, was calculated to be extremely useful.

Mr. Rawlinson hoped, that as he had not been professionally engaged at Croydon, he should not be held, even remotely, responsible for any failures there. He had been informed, that the pipes used there were thin and of bad quality. He quite concurred in the proposition, that if pipe sewers could not be laid so as to be permanent, and to keep themselves clear without being opened, to do away with stoppages, it would be better to abandon them. Experience had enabled him to arrive at some conclusions, as to the extent to which they might be used, and he had decided never again to lay down socket pipes larger than 12 inches diameter, especially if approaching a depth of 10 feet. He had experienced considerable difficulty with socket joints, and did not believe it was possible to lay them, so as to avoid occasional failures, if the diameter exceeded 12 inches. He preferred "butt" joints; and he thought that sewers constructed of hollow bricks, with radiating joints, would be great improvements on the ordinary system; in good ground the half brick would be a sufficient thickness, and in bad ground the headers would impart strength, whilst the lower range of perforations would serve as land-drains.

Mr. G. Donaldson disclaimed any intention of connecting Mr. Rawlinson's name with the sewerage works at Croydon; he spoke of the failures there from personal inspection, and

from information obtained on the spot, and as instances of the result of the injudicious use of pipe sewers.[1]

Lord Ebrington, M.P., said it was well known, that he had felt much interest in the important question of the sewerage of towns, but of course he could only look at general results, and leave to professional men the discussion of the means to be employed. Taking into consideration the great weight of the cylinder of water, contained in a large pipe sewer, when full, and the tendency, whenever there had been any carelessness in laying, to allow all that weight to rest upon the projecting sockets and joints, he conceived there would be considerable practical difficulty in laying large pottery pipes so accurately as to avoid fracture, and he had been surprised to observe, at St. Thomas-Exeter, how satisfactory the result had been, although the soil was not favourable, the supply of water was inadequate, and the outfall was bad; yet, after being at work for nine months, the pipe sewers appeared to be clear from deposit.[2] In that locality, a pipe sewer, 18 inches diameter, had been laid, where a more expensive brick construction would never have been placed at all. There were many instances in the metropolis of large brick sewers being crushed, and he apprehended, that in the construction of sewers through the made ground of streets, it was impossible to guard against such contingencies, therefore the occasional fracture of the pottery pipes should not be used as an argument for preventing their use, wherever practice showed they might be advantageously employed; and he hoped the result of the discussion of the question here, and elsewhere, would be to induce the introduction to the metropolis of a complete system of sewers, by which the drainage of the houses and streets would be more cheaply and effectually accomplished than at present.

---

[1] In the "Reports by Neil Arnott, M.D., and T. Page, C.E., on the Prevalence of Disease at Croydon, and as to the Plan of Sewerage," 4to. 1853, it is said—"We regret to state, that the result of our investigations, is a conviction, that the operations of the plan for the sewerage have been influential in producing the disease, and that the absence of proper provisions in that plan, for some of the general requirements, in town drainage, and the especial requirements of Croydon, has been productive of misfortune to the inhabitants."—[Editor.]

[2] For an account of the actual state of the sewerage of St. Thomas-Exeter see the "Report to the Metropolitan Commission of Sewers, by Mr. Bazalgette February, 1854;" Page 30.—[Editor.]

Mr. Rawlinson, in answer to questions, stated, that generally he would prefer constructing a brick sewer 20 inches diameter, to using a pipe sewer of that size, and he believed it would be cheaper. At Ormskirk, earthenware pipes, 20 inches diameter, would have cost nine shillings and sixpence per yard, where a brick sewer, 30 inches diameter, cost six shillings and six pence per yard. At Hitchen, he could not use brick drains, because it was necessary to lay only short lengths at a time, and under circumstances of difficulty, he had, therefore, in that case, waived his preference for a brick sewer above a certain size. The pipe sewer was more expensive, but it had been adopted, because a length had to be laid beneath the bed of the river, and pipes were more convenient for that locality; there was not, however, any heavy pressure upon them. With another outfall he should probably have used a brick sewer, 3 feet diameter. He objected to the system of sending men into sewers to cleanse them, and thought they should be so constructed as not to require manual labour for clearing them.

The dimensions of pipes could only be decided with reference to the nature of the material of which they were made, and the mode of manufacture. The limit of thickness for good London-made pipes was 1 inch, but those used at Manchester were 2 inches to 2½ inches thick. He believed the failures must be generally attributed to the bad material, or the careless manufacture of the pipes; some of those at Croydon were, he believed, only five-eighths inch thick, and many lengths had been laid in headings alternating with trenches, so that there were very unequal degrees of pressure upon these thin pipes, and hence the failures. The real limit of thickness was that which could be thoroughly and equally burned in the kiln, without employing such a temperature as would distort the clay. The pipes at Manchester were made of fire-clay, generally of an oval form, and upwards of 2 inches thick; which could be completely burned through. Whereas the clay used in London required considerable admixture of extraneous substances and great working, to produce pipes of such quality as were now understood to be manufactured by the best makers.

Mr. Haywood said he was glad to perceive, that the propriety of an engineer exercising his own judgment in matters of sewerage, was admitted by the Author of the paper; he had

carefully perused a number of reports emanating from the Board of Health, and they certainly left on his mind, an impression, that the empirical rules therein laid down, were required to be implicitly followed; it was satisfactory to find that this was an erroneous supposition.

The real question at issue was that of size, which would also determine that of the material to be employed, in the construction of the sewers, as there was a manufacturing limit to the dimensions of pipes, which, of course, did not exist with regard to brick structures. Up to a certain size pipes might be advantageously employed, but for the main sewers of towns, larger dimensions and other materials must be adopted. He did not concur in the principle enunciated in the Paper, which was to the effect, that the sewers of towns should not be adapted to receive excessive flood-waters, or to provide for carrying off a heavy rainfall, but that such water should pass off, over the surface, as before the construction of the sewers. It must, however, be remembered, that the condition of a town, when sewered, was very different from that of its site, previous to the building of the houses and forming the streets; artificial levels had been created, and a rainfall, or flood, which might previously have passed off innocuously, could not do so, under the altered circumstances, unless the sewers were of sufficient capacity to receive and convey away the excessive rainfall. If they were only of limited capacity, the effect would be, that as soon as they became charged and ran full bore, the excess of water, would rise in the gullies, to the level of the street, which would be flooded,—the sewers would be under considerable pressure, —the water would be forced back, up the house drains, and the basements of the houses would be inundated. It was, therefore, evidently necessary to provide for large rainfalls; and he contended, that, as a general rule, it was a better system to convey all the surface drainage, with the house sewerage, into one good sewer, rather than into two, or more pipe sewers, as in the cases of the separation of surface water from house drainage, which, he considered, it was almost impracticable to effect in a satisfactory manner.

As to the apprehended danger to the adjoining houses from the construction of large sewers, that was not a valid objection, as it was only a case of degree of width of the trench,—in both

cases the depth must be very nearly identical, and the skill of the engineer ought to enable him to guard against any casualties arising from the excavation. Mr. Haywood had laid many miles of sewers and drains, through very narrow spaces, without doing any injury to the houses.

It would only lead to error to quote the Paris system of sewers, as an argument for separating the surface-water from the house drainage; erroneous ideas prevailed as to the condition of the Paris sewerage; formerly there was an entire prohibition to any fæcal matter going into the sewers, and that prohibition existed legally to the present time; but, by degrees, exceptions were made in favour of the prisons, the barracks, the hospitals, the markets, and other public buildings, all of which had for many years communicated directly with the sewers, which debouched in the Seine, in the middle of the city. Between the Pont de Jena and the Pont de Bercy, there were the outlets of seventy sewers, discharging into the Seine. Probably all of them did not convey fæcal matters; but that a large number did so, was clearly evidenced, by the streams of sewage, running on the open shore, between the mouths of the sewers and the water-line, during the summer, when the river was low; the effluvium was intolerable in hot weather. Dr. Parent Duchatelet[1] gave copious details of the state of the sewerage of Paris, and the system adopted there, which were not only interesting in themselves, but, as proceeding from so high an authority, might be used to contravene many of the erroneous statements so industriously promulgated at the present time.

The construction of sewers generally should be looked at, with a view to the ultimate total cost; and he must contend, that if a system of town sewers was only laid down, and proportioned in size, to the house drainage-water and sullage, and entirely upon what had been very happily designated "the telescopic system," instead of the leading sewers being made large enough to carry away the storm waters, and also to admit workmen to cleanse them, it would be eventually found, that a serious and very expensive error had been committed.

Mr. Haywood was not opposed to the use of pipe sewers in

---

[1] Vide "Hygiène Publique," par A. J. B. Parent Duchatelet, 8vo. Paris, 1836.

proper situations, and under certain limitation, but he was decidedly opposed to the abuse of substituting them for brick sewers, in positions for which the latter only were adapted. He made extensive use of pipe drains for houses, taking care that they were never below 4 inches in diameter; he had, also, within the last few years, laid more than two miles of pipe sewers, within the City, and he still continued to use them, where he thought they could be employed with safety; but he was still of opinion, that a system of pipe sewers was open to serious objections, the principal of which was the liability to stoppage from deposit; in the pipe sewers, he had laid, there had been only three cases of stoppage,—the first from some deposited rubbish, the next from some fish cleanings, and the third from a breakage of the pipe; none of these would have occasioned the slightest inconvenience, if the sewers had been of larger dimensions. He did not admit, that the experience of two, or three years in provincial towns, afforded any criterion of the probable success of their application to the sewerage of the metropolis, where the conditions were as totally different as the scale of the work to be done. With a new system under trial, or, it might be said, almost under experiment, the attention of the engineer would be unremitting, but when that ceased, or diminished, the stoppages from accretion, and from other causes, would be commencing. The great objection, against pipe sewers was, that the only method of discovering the precise locality of a stoppage was by examination of the neighbouring house drains, to enable a guess to be made as to the spot; then it was necessary to open the street, to dig down to the pipes, and take up a length, and if, fortunately, the accretion was within reach of a rod, it might be removed, but if not, it became requisite to open other places, until the stoppage was discovered and remedied. Now with main sewers, sufficiently large to allow a man to pass along, the precise spot of the stoppage was discovered, without delay, or expense, or any annoyance to the neighbourhood. It was admitted, that it was not desirable to send men up sewers, and even that accidents had occurred; but neither was it pleasant for a miner to be obliged to go daily down a pit, where there was generally more, or less, of inflammable air; society was, however, so constituted as to demand for its necessities, or its luxuries,

much that was not pleasant, and, in the case of sewers, if they were ventilated and maintained under such a system as would enable them to be traversed at given periods, so as to prevent accumulation, there was less objection to the labour, than might be imagined, and, even with a considerable first outlay, it would eventually be found a cheaper system, to have sewers of adequate dimensions and certain action, than pipes of restricted dimensions, if their action produced only uncertain results.

In practice he found, that pipes once removed, or broken into, could rarely be relied on again, as it was difficult to make good the joints, and to maintain the original level; especially where the gradient was slight, and the accretions were, therefore, likely to take place again. Where there was not a rapid fall, a pipe of 4 inches diameter could not evidently afford any margin for accumulation, and in cases of limited fall, he had almost invariably found a tendency towards stoppage, where there was not a very considerable flow of water. It was admitted, that the pipes required great care in laying,—that in many cases it was requisite to bed them in cradles, to prevent their being broken,—and that it was requisite to establish ventilation for them, although it had been originally stated, that it was not necessary.

In the published accounts of works, at various provincial towns, there appeared some good illustrations of the practice of experienced engineers who had devoted time and attention to the subject. At Liverpool, Mr. Newlands (Assoc. Inst. C. E.) the Borough Engineer, had only used pipe sewers to a limited extent, and under circumstances apparently precisely analogous to the practice hitherto adopted in the metropolis.

In three years, beginning in 1847, and ending December 1850, there had been constructed at Liverpool:—

	Ft.	In.		Lineal Yards.
Brick sewers	6	0	high	1,103
„	4	6	„	3,467
„	3	6	„	6,594
„	3	0	„	11,493
„	2	9	„	6,749
			Total . . .	29,406
Pipe drains	15 inches diameter		. . .	252
„	12 „ „		. . .	335
			Total . . .	587

These figures indicated significantly Mr. Newland's opinion, and it was understood, that he still used pipe sewers, only in exceptional positions, where he was convinced there would be little liability to stoppage.

At Leeds, Mr. J. W. Leather (M. Inst. C. E.), the Engineer for the town, only used pipe sewers for courts and minor streets, and then almost invariably in positions where they could be connected directly with sewers, up which men could pass.[1]

At Birmingham, in the extensive and well-conducted system of sewerage, under the control of Mr. J. Pigott Smith (Assoc. Inst. C.E.), the Borough Engineer, pipe sewers had been tried and were only used to a very limited extent. The practical experience of large towns only had been cited, because, as had been repeatedly stated, the "telescopic system," of pipe sewers, which might, under favourable circumstances, suffice for a small country town, could not form a precedent for the sewerage of the metropolis, which, at last, was the main consideration.

It was necessary to allude to the opinions of Mr. John Roe (Assoc. Inst. C.E.), who, for a very lengthened period, held the post of Surveyor of the Holborn and Finsbury district of sewers. His Reports showed, that the cost of cleansing small drains, was greater, than the expense of constructing an efficient sewer; and that no amount of water sufficed to cleanse a small pipe drain, if it once became stopped; but that in a large sewer, flushing and other means could be effectually adopted, without any inconvenience being experienced on the surface. Mr. Haywood then read the following extracts from Mr. Roe's Reports:[2]—

"*January* 29, 1847.

"The desire of some persons to effect a further saving has led to the advocacy of drains, or small sewers to be placed in streets, or roads without discrimination. Others advocate two lines of small sewers, or pipes, one on each side of a street, to receive the drainage; but as two such small sewers would not carry off the surface drainage, in all cases, other parties con-

---

[1] The "Report by Dr. Arnott and Mr. Page on the Prevalence of Disease at Croydon" gives an interesting comparison between the pipe sewers used at Leeds and at Croydon. Pages 41 and 42.—Editor.

[2] Vide "Report to the Commissioners of Sewers for the Holborn and Finsbury District," 8vo, London, 1847, page 6.

sider, that one line of sewer should be formed for the surface, and another for the house drainage. In practice this would be found unnecessary, as regards any advantage to the sewer water for manure, and as regards expense, it would, besides causing an immediate extra outlay, entail a perpetual annoyance and charge. A fact that will serve to illustrate this, is that of the new sewer lately built in Hoxton Town. On each side of Hoxton there was a line of small sewers in front of the houses. The cleansing of these and other small sewers have cost, on an average, one shilling and threepence per foot lineal, each time of cleansing. Taking fifteen such sewers, the average time of cleansing has been four years and a half, and reckoning the first cost of the two small sewers, with the cleansing, the cost, in about twenty years, would have amounted to the expense of constructing an efficient sewer."

"This Commission has caused a new sewer to be built in Hoxton Town, which will require no repairs for more than a century. The saving to the public, therefore, by constructing an adequate sewer, and thereby doing away with the two inefficient ones, will be double the amount that the new sewer has cost."——

At page 7 of the same Report it was said, "After many years' experience your Surveyor begs to state, that except a sewer has an extraordinary inclination, or has a body of water passing along it, with a considerable velocity, deposit will accumulate. If a small sewer, or drain be choked with filth, no water will wash it clear, but the deposit must be raised and removed by manual labour; but if two, or three feet (in depth) of deposit is accumulated in a sewer, large enough for a man to pass through, (your new sewers ranging from 3 feet 6 inches to 5 feet in height in the streets), such deposit could be washed away in the manner adopted in your own sewers."——

Again, in an extract from Mr. Roe's report upon the sewerage of Southampton, in 1845, quoted in Mr. Ranger's subsequent report upon that borough, February 1850, it was stated, "I would observe generally, that in an extended drainage it will be found ultimately a saving to the public, to make them large enough for a man to pass through them occasionally, except where the inclination is so great, and the supply of water so plentiful, as to insure their never requiring to be opened."——

Such were Mr. Roe's opinions in 1845 and 47; as, however, the extract had been read as given in Mr. Ranger's report, it would only be proper to add a statement, made by Mr. Ranger, upon the same subject, as in that report, directly after the above quotation of Mr. Roe's opinions, it is said, "It is due to Mr. Roe to state, that I have good reason to believe subsequent experience has convinced him, that the system was not the correct one, and he would now adopt a different mode."

Now Mr. Haywood thought, that if Mr. Roe had really altered his opinions, it must have been very recently, and only since he became one of the officers of the Metropolitan Commission, and was retained by the Board of Health, and it was important to inquire into the reasons which, after so many years' previous practice, had so suddenly convinced him, that the system he had previously acted upon was so utterly erroneous. Indeed he was inclined to suspect there must be some error in the statement, and until Mr. Roe himself stated his recantation of those principles and gave his reasons, Mr. Haywood would prefer remaining in the belief, that Mr. Roe's real opinions were still those which he had recorded, when he was an independent officer of the Holborn and Finsbury commission, perfectly unfettered and free to pronounce his opinions, whether they clashed with those of other persons, or not. But even admitting, for the sake of argument, that Mr. Roe had changed his opinions, he could not alter the facts with which his reports abounded, and all of which were strongly in support of the opinions he originally entertained.

It had not been stated, by Mr. Rawlinson, what formulæ he had used, for calculating the sizes of his pipe sewers, although he had recorded his non-accordance with certain accepted formulæ and tables, on the ground of their giving too large a sectional. If this uncertainty as to the correctness of formulæ was admitted, the profession would soon be at a loss to determine whose formulæ should be used; whether those of Phillips, Roe, Austin, Cowie, Cresy, or Ranger, or those derived from the experiments made by Messrs. Lovick and Medworth, for the Metropolitan Commission of Sewers; all these gentlemen objected to hitherto-received formulæ, although it did not appear, that anything very uniform, or satisfactory had been substituted for the results of the researches of Du Buat, Eytelwein, Prony,

Hawksley, and others, which it was the fashion now, either actually, or inferentially to condemn; and it was of vital importance to ascertain, whether these experimenters, whose works had hitherto been looked upon as of standard character, were really still deserving of confidence. It was incumbent on those who unsettled creeds to supply worthier articles of faith.

Mr. RAWLINSON said, he feared some parts of the paper had failed to convey the impression he had intended. It must be borne in mind, that there were still many places of considerable population, without any adequate system of sewerage, where the rainfall passed away by surface drainage to the natural outfall; now if that was not improperly tampered with, but rather assisted by artificial means, the excessive rainfall might be provided for in such a manner, as also, eventually, to assist any system of house drains and sewers which might be constructed. In fact, the question of applicability of system to situation should never be lost sight of.

Mr. J. MURRAY said, that tubular drains had lately been extolled, as being superior to brick sewers, because their form, their interior smoothness and other qualities, rendered them capable of discharging greater quantities of water, and also less liable to accumulate deposit. This opinion was based upon the results supposed to have been arrived at by a series of experiments, instituted by and made for the former Metropolitan Commission of Sewers, ostensibly for the purpose of testing the correctness of the accepted hydraulic formulæ. It was stated, that the quantity of water, discharged through the pipes, had been accurately measured, and the actual discharge had exceeded the calculated quantity in the ratio of 3 to 2; this result was accepted and it was concluded, to reduce the capacity of the sewers in that proportion. In consequence, these experiments had been published in the Reports, issued by and under the sanction of the General Board of Health, and had been acted upon by the Inspectors, in their official capacity.[1]

It appeared, that the experiments were made on lines of pipes of 50 feet and 100 feet in length, and of 3 inches, 4 inches,

---

[1] Vide "Report on the Supply of Water to the Metropolis," Appendix No. 2, page 185; and "Minutes of Information," General Board of Health, 1852, page 39.

and 6 inches diameter; laid perfectly straight, and at different gradients; consequently the quantity of water discharged from them would, necessarily, exceed the volume which could pass through lines of pipes, having curves of such various radii as would be met with in the streets of a town.

The experiment at Hitchin[1] was equally fallacious. An earthenware pipe 15 inches diameter was there temporarily laid, with an inclination of 8 inches in a length of 235 feet = a fall of 1 in 352½; the stream of water was stated to have been wire-drawn, at 10 feet from the upper end, to 14 inches,— at mid-distance to 11 inches, and at the outlet to 6 inches, when the inlet was just covered with water. The velocity of the stream was measured at 188 feet per minute, and the quantity of water discharged was 1025 gallons, or 164 cubic feet per minute. This pipe was also laid perfectly straight and at a uniform inclination, and therefore the result would be greater, than if there had been the ordinary practical irregularities of bends, &c. The discharge according to Prony's formula would be 210 cubic feet per minute.

Mr. Murray was not prepared to admit either the accuracy of the results, or that such diminutive experiments could impugn the formulæ of Du Buat, which were based on an extended series of experiments, performed with all the care and skill of men of acknowledged scientific attainments, and accustomed to minute observation; whereas the operators for the Board of Health evidently did not possess the necessary qualifications for the investigations which had been intrusted to them. The simple formula of Prony, was founded on a selection from the experiments of Bossut, Couplet, and Du Buat; the formula of Eytelwein was deduced from the same source, and that of Poncelet, investigated by Navier, gave similar results.

Mr. Murray had prepared the following table, showing the delivery of water, by pipes of small and of large dimensions, through moderate and more extended lengths and under various pressures, and he contended, that far from throwing discredit upon the researches of the experimenters, whose works he had mentioned, the accuracy of the formulæ had been satisfactorily confirmed by practice.

---

[1] Vide "Minutes of Information," General Board of Health, 1852, page 78.

DISCHARGE THROUGH PIPES, calculated by several Formulæ.

Diameter of Pipe.	Length.	Head or Pressure.	Discharge per Minute.	Calculated Discharge per Minute.	——
Inches.	Feet.	Feet.	Cub. Feet.	Cub. Feet.	
2	3,300	12·75	1·617	1·507	Du Buat.
—	—	—	—	1·609	Prony.
—	—	—	—	1·509	Eytelwein.
—	—	—	—	1·59	Poncelet.
4⅓	14,930	51·00	11·333	11·252	Du Buat.
—	—	—	—	11·491	Prony.
—	—	—	—	10·784	Eytelwein.
—	—	—	—	11·281	Poncelet.
12·789	3,837	12·90	155	158	Du Buat.
—	—	—	—	155	Prony.
—	—	—	—	145	Eytelwein.
—	—	—	—	141	Poncelet.
12·789	14,963	21·582	111	99	Du Buat.
—	—	—	—	102	Prony.
—	—	—	—	99	Eytelwein.
—	—	—	—	98	Poncelet.
19·184	5,052	4·929	217	223	Du Buat.
—	—	—	—	230	Prony.
—	—	—	—	215	Eytelwein.
—	—	—	—	226	Poncelet.
30	5,280	9·00	880	926	Du Buat.
—	—	—	—	932	Prony.
—	—	—	—	865	Eytelwein.
—	—	—	—	910	Poncelet.

In explanation of the table it was stated, on the authority of Dr. Robinson,[1] that water was brought into the town of Dunbar, in East Lothian, from a spring, through pipes, the first length of which was 1100 yards, of 2 inches diameter, with a declivity of 12 feet 9 inches;—

The actual quantity discharged was 1·617 cubic foot per minute.

The mean calculated quantity was 1·5539 cubic foot per minute.

Again it was shown by Mr. Jardine,[2] that the main pipe of the Edinburgh Water Works, extending from the fountain head, at Comiston, to the reservoir at the Castle Hill, Edin-

[1] Vide Robinson's "Mechanical Philosophy," vol. ii., page 441.
[2] Vide Brewster's Encyclopædia, Art. "Hydrodynamics," page 526.

burgh, was of lead throughout, 14,950 feet in length, $4\frac{1}{2}$ inches in diameter, and the head was 51 feet above the point of delivery.

The maximum discharge, during five consecutive years, was 11·333 cubic feet per minute.
The mean calculated quantity was 11·202 cubic feet per minute.

The next three results were taken from Bossut's Treatise on Hydrodynamics, brought into English measures, and they were stated to be his own experiments, combined with those of Couplet. The pipes were of iron with several horizontal and vertical bends, which were taken into account in the lengths mentioned :—

	Cubic Feet per Minute.	Mean calculated quantity.
The first yielded	155	150 cubic feet per minute.
The second	111	99·5 " "
The third	217	223·5 " "

The last statement of the table was obtained from the late Mr. Chapman, C.E. of Newcastle; but whether it was derived from actual measurement, or was simply the result of his experience, was uncertain. From a pipe of 30 inches diameter, with a fall of 9 feet per mile, the actual quantity discharged was 880 cubic feet per minute.

The mean calculated quantity was 908 cubic feet per minute.

The following were the formulæ employed in the calculations of the table :—

Du Buat's Formula reduced to English Measure.

$$V = \frac{307(\sqrt{R} - 0\cdot 1)}{\sqrt{S} - L(\sqrt{S + 1\cdot 6})} - 0\cdot 3(\sqrt{R} - 0\cdot 1).$$

V = velocity in inches per second.
R = hydraulic mean depth = $\frac{1}{4}$ diameter.
S = slope or difference of level.
L = hyperbolic logarithm, and found by multiplying the common logarithm by 2·3026.

In the following formulæ English feet were employed :—

V being the velocity per second.
D " diameter
H " head or pressure } of the pipe.
L " the length

Prony's simple Formula.

$$V = 48 \cdot 449 \sqrt{\frac{DH}{L}}.$$

Eytelwein's Formula, as given by Tredgold.[1]

$$V = 45 \cdot 5\left(\sqrt{\left(\frac{DH}{L + 47D}\right)}\right).$$

Poncelet's Formula.

$$V = 47 \cdot 95 \sqrt{\left(\frac{DH}{L + 54D}\right)}.$$

Mr. Hawksley had also repeated some of the experiments, for his own satisfaction, and in all cases had found them accord with the results anticipated by the calculations, based on the formulæ, which appeared now to be condemned. In the same manner he had repeated some of the Board of Health experiments, and had, in their case, been as unfortunate in the results, as he had been happy in the previous cases, for in all instances he had found the experiments, based on the Blue Book reports, entirely wrong and totally at variance with fact. As a proof of the correctness of the formula he was in the habit of using, he stated, that where Mr. Roe's practical tables would lead to the adoption of a sewer of 48 inches in diameter, his formula gave 49 inches, and in another case, the approximation was as near as 120 inches to 124 inches. Some trials, on a main of pipes 13 inches diameter, and nearly 3 miles long, near Whitehaven, had also verified the accuracy of the formula, in which he was able to place implicit confidence. He could not agree with Mr. Rawlinson's proposition, that the size of the sewer outlet should be in proportion to the number of houses; this might be the case, if all surface drainage was rigidly excluded from the sewers; but in almost all cases the real question was, the area to be drained, and whether that surface was covered with roofs and paved courts, or roads and gardens. In case of sudden storms, the water would pass off rapidly, and must be conveyed away by sewers, or else the basements of the houses would be flooded. The documents issued by the Board of Health, instead of furnishing practical rules for enabling a district to be cleared of the water falling on it, appeared to be chiefly occupied with the attempt to discourage the application of previously accepted rules, and to be devoted to persuading the

---

[1] Vide Tredgold's "Tracts on Hydraulics," page 215.

public, that the only sewage to be conveyed away was the foul house-water; now it must be admitted, that this was too limited a view for the present age, in fact it was a deplorable state to be left in, and would not be suffered to prevail. Partial success might, for a time, be obtained; but the undue substitution of small pipes, for proper-sized sewers, would eventually lead to serious failures and accidents, and after considerable expense had been incurred, they would be obliged to recur to main sewers of properly-proportioned sections; and he believed there was no instance of any town, so sewered, having been permanently inconvenienced by any amount of rainfall. The most serious inconvenience had not always been found to arise from a sudden and heavy fall of rain, of short duration, but more frequently from a prolonged fall, of less hourly amount; and, in such a state of things, the limited capacity of pipe main sewers had, already, been productive of serious inconvenience. The experienced practical Engineer would, therefore, provide sewers of sufficient dimensions for the conveyance of water, under all the ordinary circumstances of heavy and continued rains, and be governed by the amount and value of the property to be endangered, or improved, in determining the magnitude requisite to meet special necessities.

Mr. Rawlinson stated, that other Engineers, besides those connected with the Board of Health, were in the habit of using pipe-drains;—for instance, they were employed at Durham, to a considerable extent, by Mr. Hawksley.

Mr. Hawksley explained, that earthenware pipes were, in his opinion, very useful for the drains of houses, courts, and minor thoroughfares, but not for main sewers. Durham was not an instance in point, because that city was, for the most part, built upon ridges, and the streets were, in consequence, so precipitous, that the sewers were required for little more than conducting away the drainage from the houses, and the surfaces of comparatively narrow streets. There were also many outfalls into the river, and the separate drainage areas were therefore small. Yet, notwithstanding these peculiarities, the system, so rigidly enforced by the Board of Health, had compelled him to employ pipe drainage to a greater extent than he thought advisable, and it was only by so far adopting the dicta of that Board, and after a serious loss of time, that he had been enabled to get his plans passed by the General Board, as a preliminary

to their consent for power to borrow the money necessary for the execution of the work.[1] He must contend against the manifest injustice of this system, and it was easy to predict the serious consequences that would inevitably result from it.

Mr. Netherway said, that as the success, or failure of pipe sewerage principally depended on the strength of the earthenware pipes, he had tried some experiments, with the view of ascertaining what weight they would bear. Each experiment was tried upon two pipes laid parallel to each other, with an interval between, and bedded in gravel, up to two-thirds of their diameter. A saddle of the length of the pipe, curved to fit the surface, was laid in each, so as to distribute the weight throughout the length, and the load was increased gradually. It would suffice to give the results of two trials. Two Staffordshire blue pipes (Haywood's make), each 2 feet 4 inches long, 12 inches diameter, and $\frac{13}{16}$ths of an inch thick, sustained a load of 46 cwt., or 23 cwt. on each pipe; under this weight one of the pipes gave way, and split longitudinally into four, nearly equal, portions. The other pipe was only slightly crushed on the top, at one end.

Two London glazed pipes (Doulton's make), each 2 feet 2 inches long, 12 inches diameter, and of a mean thickness of nearly $\frac{11}{16}$ths of an inch, were tried in a similar manner, and one of them was crushed exactly as in the previously described experiment, but with a much less load, being only 28 cwt., or 14 cwt. on each pipe.

Mr. Doulton said, it must be borne in mind, that the manufacture of earthenware pipes, for sewers and house-drains, was of recent introduction, as they had not been generally used, until within the last four, or five years; the first demand being rather sudden, and exceeding the supply, the manufacture was undertaken by persons only imperfectly acquainted with it, and it was only by experience that improvements had been introduced, and the present quality had been attained.

Considering the quantities of earthenware pipes now made, the failures had been very few; and some idea of the extent to

---

[1] Vide, on this subject, "Remarks on the Dictatorial Interference of the General Board of Health," &c., 8vo, Tract, London, 1852; and "A Letter to the Marquis of Chandos, M.P., in relation to the exercise of some of the extraordinary powers assumed by the General Board of Health," &c., by T. Hawksley, 8vo, Tract, London, 1853.—Editor.

which they were adopted might be arrived at, from the statement that Messrs. Doulton now produced, at their various manufactories, about 18,000 yards per week, and had for the last four years made very large and increasing quantities. Other manufacturers had also manufactured similar pipes very extensively, and it would be strange, considering the novelty of the application, the inexperience of those using them, and other causes, if some failures had not occurred; they did, however, bear but a small proportion to the very large quantity used. The chief demand was from those who had partially introduced them, and claimed to have had practical experience of their efficiency.

There was not any practical difficulty, in making stoneware pipes up to 18 inches diameter, true in form and sufficiently strong to resist any pressure they were at all likely to be exposed to; but in the present state of the manufacture, it was not desirable to go beyond that size.

Many pipes, particularly of the larger sizes, had been made of insufficient strength, arising either from bad material, imperfect vitrification, or insufficient substance. Thousands of pipes of 18 inches diameter, and of little more than half an inch thick, had been laid, and failures, in many cases, had naturally resulted. Thickness alone was not a correct test of strength, and unless the body of the pipe was of close texture and well vitrified, it would be weak as well as permeable. It was easier to make a very thick pipe, of loose and open substance, than to produce a pipe of moderate substance, close and well vitrified throughout, which would resist more pressure, than one much thicker, only imperfectly vitrified. There was a danger, that if pipes were required too thick, the material would be deteriorated and more would be lost, by looseness of texture, than would be gained by the additional substance. The quality of pipes should be tested by an examination of the body after fracture. A good surface was no indication of a good pipe; when broken it should resist all attempts to scratch, or cut it with a knife.

Complete impermeability was stated to be a necessary qualification for good sewer pipes, and could only be secured by thorough vitrification; in that respect stoneware drain pipes had an advantage over the most perfectly constructed brick sewers, which were generally porous. Mr. Rawlinson thought

an impermeable brick could be obtained, if so, it would lessen the objection to brick sewers, though it was impossible to overcome the difficulty arising from the joints.

From their internal smoothness and regularity, pipes could be used of smaller sizes, than brick sewers, under similar circumstances.

There were numerous causes of failure, apart from the manufacture of the pipes,—such as improper application, imperfect laying, and the system of partly tunnelling and partly trenching. The latter practice was very objectionable, in consequence of the irregular settlement of the earth, when filled in, the pressure bearing only on some parts of a long line of pipes, rigidly laid; they were, therefore, liable to be broken, by the powerful leverage.

Lengths of 3 feet each were not so strong as those of 2 feet each; and the occasional introduction of half-socket pipes would relieve the pressure, where the settlement was irregular.

Actual works had been referred to, as giving the best test of the efficiency of pipes. Messrs. Doulton had supplied pipes for the complete drainage of nine, or ten towns, all of which were stated to have succeeded; among them was St. Thomas-Exeter, referred to by Lord Ebrington, as a very satisfactory work.[1]

---

[1] Mr. Bazalgette (the Engineer to the Metropolis Sewers) has since examined and given an account of the condition of this and other towns, in his "Report to the Metropolitan Commission of Sewers, upon the Drainage and Water Supply of Rugby, Sandgate, Tottenham, St. Thomas-Exeter, and Barnard Castle (1854)." It is therein stated, "I am now enabled to report, that the result of my inquiries and observations, on the application of the tubular system of drainage, in these five places, affords no proof of its applicability to the Metropolis, and no evidence of the cheapness and efficiency of the works at these five places, which should entitle the system to serious attention, with reference to the works to be undertaken for drainage in London."——

"The Reports (of the Inspectors of the General Board of Health) to Viscount Palmerston, upon Rugby, Sandgate, Tottenham, the parish of St. Thomas-Exeter, and Barnard Castle, would appear to give the result of the experience of the house drainage of those places, through pipe sewers, for the last two, or three years; but upon a more close investigation, it appears, that the main sewers only were, during that period, completed,—ready to receive, it is true, but not then actually receiving, the house drainage, or at most but an inconsiderable portion of it. About two years since, the drainage of the houses only commenced being turned into the pipe sewers, and this work is not yet completed; so that up to the present time, those places, even if no failures had occurred, would afford no real experience upon the subject."—EDITOR.

Rugby was among the first towns completely drained by tubular earthenware drains; upwards of 6000 feet of pipes, 18 inches and 20 inches diameter, were laid in cuttings, even as much as 28 feet deep; they had been down about eighteen months, and though less in substance, than those now being made, they had resisted perfectly all pressure on them.

Mr. Doulton then read an extract from a letter from Mr. Phillips, the local Surveyor, dated Rugby, 27th November, 1852:—

"As far as our system of drainage has been adopted, the result has been highly satisfactory. What the exact number of houses may be, whose sewage matter traverses the new sewer, I cannot say, as during the laying of the pipes a vast number of houses were necessarily connected, in consequence of the old system of drains having been taken up; there are however upwards of four hundred houses enjoying the combined system of drainage and water supply, which have been connected under my own supervision, the drains being all newly laid with pipes exclusively. We have not yet had more than one instance of fracture in the sewer, and that owing to a fall of earth, the substratum having been washed away by an old culvert; this is also the only case of stoppage."[1]

---

[1] The following extracts from a "Report to Viscount Palmerston, upon the System of Drainage pursued in the Metropolis; by R. Jebb, Chairman of the Metropolitan Commissioners of Sewers, 8vo, London, 1854," convey considerable information respecting Rugby, St. Thomas-Exeter, and the other towns; as also valuable opinions as to the use of tubular pipe sewers for large cities:—

"By order of the Commissioners, their Engineer, Mr. Bazalgette, visited Rugby, Sandgate, Tottenham, St. Thomas's, Exeter, and Barnard Castle, and in his Report, are embodied the results of his observations with regard to the nature and expense of the works there executed; those results being such as to qualify the conclusions which might, without explanation, be drawn from the Reports of the Local Boards of the places named. From his Report the following facts may be collected: that in each of the five towns there is a double system of sewers,—1°, a set of old brick sewers, originally constructed for surface drainage, and now maintained for that purpose, out of the public rates; 2°, a set of newly-constructed pipe sewers, chiefly, or exclusively for the reception and discharge of house-drainage. The entire sewerage of the town comprehends both sets of sewers; and its cost is really the cost of both, and not the cost of the new pipes merely, as a person deriving his sole information from the Reports, sent to your Lordship, might possibly suppose. I may here remark, that a like observation applies to several other places, drained under the supervision of the General Board of Health, where pre-existing brick sewers are still maintained, and used as a part of the system of sewerage;

In order to satisfy himself as to the strength of well-made pipes, Mr. Doulton had caused a series of trials to be made, of

---

whilst the Reports, holding up the drainage works in those places as models of cheapness, make mention only of the new works.

"At St. Thomas's, Exeter, as respects a considerable part of the town, the average cost per house of putting in house-drains, &c. would appear, on the face of the Report from that place, to be exceedingly low. This apparently low average is obtained by dividing the entire cost of all the house-drains amongst the houses, whether drained, or *undrained*. Mr. Bazalgette (Report, p. 33) estimates the proportion of the undrained houses at about half the entire number.

"It further appears from Mr. Bazalgette's Report, that the cost of executing works of the same character is necessarily greater in London, than in the five towns referred to. This arises from two causes:—First, all kinds of workmanship are dearer in London, than in country towns. This observation cannot apply to Tottenham, but it applies to the other places. Secondly, and chiefly, —in London there are several heavy items of expense, which either do not occur at all, or occur in a very slight degree, in country towns. In London, sewers, whether of pipes, or of brick, must generally be laid at a much greater depth; the trenches carefully fenced, watched, and lighted; the large and weighty and closely-packed houses shored up; gas and water pipes protected and made good; and costly pavements removed and restored. These, and like matters, add very materially to the expense of making sewers in London; and the amount is but little affected by the nature of the structure."

"It is important to observe, that the cost of sewering a town is not simply in the ratio of its size."——

"As to the alleged efficiency of the works: from Mr. Bazalgette's Report it appears, that in none of the five towns named have the works of *private* drainage been commenced more than two years and a half; in some they have been commenced much more recently; and in none are they yet complete. In none has sufficient time elapsed to give the system a full trial. In four, out of the five, towns there have been failures; at Sandgate to a considerable extent."—

"In a small country town, not already provided with surface drains, you may often, with comparative safety, allow the rain to a great extent to flow over the surface of the streets, or along the open side channels, till it reaches the nearest ditch, or brook, especially where, as is frequently the case, there are no basements to the houses. In London, the *whole* of the surface drainage is, or ought to be, carried to its ultimate destination in covered channels under ground, which must be deep, on account of the basements, and for other reasons."

"The amount of surface drainage is measured by the quantity of rain which falls. Whatever may be the case in small country towns, in London it will not answer to provide sewers for merely ordinary rain-falls, not exceeding at any time a quarter of an inch per diem: provision at the rate of two and a half inches per diem must be made for storms. This rate will give for the entire metropolitan area 114 square miles, under the jurisdiction of the Commissioners, 662,000,000 of cubic feet per diem, the quantity for which surface drainage sewers ought to be provided."——

"Assuming, for the moment, that all the London sewers could at all times be rendered 'self-cleansing' and self-repairing, so as to render it unnecessary for

more severe character than tubes would ever be subjected to practically. The pipes experimented on were 2 feet long;

---

men ever to enter them, then the question of size becomes simply an hydraulic question."——

"The Commissioners have not accepted the hydraulic tables which are understood to be adopted by the Board of Health, those tables being in a large measure at variance with the results both of science and experience, English as well as Continental, and being such as, if adopted for London, would entail the most serious consequences to the health and property of its inhabitants, by giving rise to the construction of sewers too small to answer the purposes intended."——

"When deposit does form in the large brick sewer (and this will now and then happen, not only in brick, but also in pipe sewers), the means are at hand of entering it, and removing the obstruction, without the necessity of breaking up the street,—a highly inconvenient as well as costly expedient in London."—

"For those sewers near the river, the justification of their size rests upon the absolute *necessity* I have before pointed out, of men being enabled to enter and cleanse them; for those higher up, a good reason is offered, in the general principle advocated by Engineers—that inasmuch as every machine, however perfect, is liable to occasional derangement, each part of it ought, if possible, to be rendered easily accessible for the purpose of repair, or adjustment."——

"The Commissioners have no objection to back-drainage abstractedly: their substantial objection is to the dangerous and disastrous notion, of attempting to substitute it for the important street sewers already described. They permit it in many cases. Applications for leave to adopt it are made almost daily, and the Engineer has very seldom been obliged to refuse permission for its adoption. But, in truth, the system is not a favourite one with the more respectable London builders, who prefer a separate drain for each house, running under the latter, and then half way under the street, into the sewer in front."——

"It is found, that the 4-inch pipe stops, and the 20-inch pipe breaks. The Commissioners have come to the conclusion that it is not expedient to use pipes smaller than 6, or larger than 12 inches in diameter."——

"The Commissioners prefer 6-inch pipes, because, whilst the difference of cost is very trifling, and whilst the loss of scouring power is practically insignificant, the 6-inch pipes allow more readily of the passage of those innumerable substances, which are so often 'improperly admitted,' and which will continue to be improperly admitted by careless, or mischievous persons."——

"The restriction, placed by the Commissioners, upon the use of pipes for small sewers, except in certain favourable situations, has been based, not upon any objection to pipes abstractedly, but upon their proved insufficiency in point of strength. The manufacture of them, however, has, within the last twelve months, been materially improved, owing to the regulations of the Commissioners themselves. A year ago, the best pipes procurable were generally too thin, to be safely used under roads: they are now better, the Commissioners having succeeded in inducing the manufacturers to make them of good material, and well burnt, 1½ inches thick; and the Lambeth manufacturers are now preparing to make them still thicker. When this is accomplished, it may fairly be anticipated, that the use of them may be safely extended, to situations where the Commissioners have been hitherto under the necessity of constructing small half-brick barrel sewers."—EDITOR.

each pipe was supported at the ends on blocks; a piece of wood 12 inches long was then laid on the middle, and the weight was gradually increased until fracture ensued.

The following were the results:—

Diameter of Pipes.	Thickness.	Weight on 12 inches square. — Broke.		Weight over the entire surface of the Pipe.		
Inches.	Inch.	Cwt.	qrs.	Tons.	cwt.	qrs.
18	$\frac{7}{8}$ $\frac{1}{16}$	53	3	14	2	1
15	$\frac{7}{8}$	31	3	7	1	1
12	$\frac{3}{4}$ $\frac{1}{16}$	53	3	8	13	2
12	$\frac{3}{4}$ $\frac{1}{16}$	71	0	12	12	0
9	$\frac{3}{4}$	64	3	8	18	3

Mr. Ritchie had taken great interest in the sewerage of Edinburgh, and had carefully watched the trials of the new system; after the experience of a year it had been declared to be an entire failure, chiefly on account of the silting up of the pipe drains, which were too small,—of the repeated stoppages and the consequent inconvenience to the public, from breaking up the streets. A report of a sub-committee of the Paving Board, of Edinburgh,[1] gave some useful information, as to the employment of pipe drains in some of the wynds of the city. It stated, that the complaints were generally well founded; the tubular drains, especially where there was only little declivity, though laid at considerable depths below the surface, had been repeatedly choked up,—and had occasioned considerable expense and inconvenience, in opening the ground to remedy the defects;—the effluvium traps, though numerous, were defective, and were constantly stopped up by surface mud; —the bent tubular drains, serving as connexions with main sewers, where the latter existed, were inefficient, as the matter hardened within the bent portion, and it became necessary to open the ground and break the pipes, to do away with the stoppage and then to replace them. The Report stated the Committee to be of opinion "that the tubular system of drainage

[1] Vide "Report on Surface Drainage, by a Sub-Committee appointed by the City of Edinburgh Paving Board," 20th September, 1852, R. Ritchie, convener.

does not appear applicable, or well adapted to many portions of Edinburgh, where no constant supply of water exists to flush the drains, as the liquid which finds its way into the drains, from the street gutters, is always mixed with refuse and mud, which must soon choke up any small tube, more especially if there be bends in it, or if its position be at all horizontal. The Sub-Committee think it proper to state, that from every inquiry they have made, probably all the tubular drains, laid down under the provisions in the Police Act, are liable to the objections pointed out, and may ultimately entail, from their liability to obstruction and difficulty of being cleansed, considerable expense upon the inhabitants." And it recommended, that all main sewers should be so constructed as to be accessible for manual cleansing, if necessary.

Mr. Parker was of opinion, that the most probable cause of the failures of the tubular drains might be traced to carelessness in laying them; it not unfrequently occurred, that they were merely laid down in the bottom of the trench, with the shoulder of the socket resting on the ground, no care being taken to ascertain whether the ground was rammed under, so as to pack up and support the body of the pipes, and of course fracture ensued, when any weight was brought upon them. Now all pipes should be well bedded in mortar, in clay, or in screened sand; and the sides of the trench should batter, or incline towards the surface, in order to receive some of the pressure of the ground, when filled in and rammed.

He had seen such extraordinary instances of accretion in sewers, and drains, that he feared cases of stoppage would constantly occur in small tubular drains; and the substances found in them were so heterogeneous, that it was impossible to conceive how they arrived there. In most cases they caused accretion, which could only be removed by opening the street and breaking the pipes.

Mr. Bazalgette fully coincided with that portion of the paper, where the Cloaca Maxima, with its massive ashlar, dovetailed joints and pozzuolana mortar, was held up as an example of that stability and durability, which, he admitted, was most desirable for the sewers of cities, on account of efficiency, of public convenience and of ultimate cost; but he was surprised to find, that this just admiration of the solid structures of ancient

Rome, dwindled into the recommendation of the use, for the sewers of modern London, of fragile clay pipes, which, instead of enduring for centuries, were not unfrequently crushed, within a few months of their being laid, and, if they escaped that fate, were generally stopped up by deposit, and were obliged to be broken and be replaced, within a few years.[1] Such a system could not obtain for the main sewers of a great city, even if it might, in some instances, be made to answer for a small country town,—there could be no analogy between such cases, and he was convinced, that it would be eventually cheaper, for the authorities in London, to construct good accessible sewers, through which men could pass at stated periods, to prevent, or to remove accretion, than to be under the necessity of constantly opening the streets to search for stoppages, without regard to the cost and the inconvenience entailed on the public. He believed it was the want of scientific and practical knowledge, upon this difficult subject, which had induced unprofessional amateurs to adopt and propound theories, which, however plausible, were at variance with the laws of Nature, and to attempt to lay down general rules as applicable under all circumstances; forgetting, that the natural features and the variety of wants of different towns, continually called into requisition the deepest science and experience of able engineers, who had devoted their lifetime to the study of the subject, and that the application of any general laws was thus precluded.

He denied, that, as a general rule, pipe sewers were, as had been asserted, more " economical and efficient," than brick sewers, or that a saving in the first outlay, supposing it could be effected, by the construction of pipe sewers, must tend to ultimate economy. He contended, that the assertion of pipe sewers being " self-cleansing," and brick sewers being " sewers of deposit," was incorrect, and he undertook to prove, both by theory and fact, that the advantage, in point of self-cleansing powers and non-liability to obstruction, was in favour of the system of brick main sewers. He totally dissented from the statement, of the

---

[1] Vide " Report to the Metropolitan Commission of Sewers, relating to the Application, State, and Examination, of Tubular-Pipe Drains, or Sewers in the Metropolis." By J. W. Bazalgette. 4to. London, June, 1835. Also, " On the Main Drainage of London." March 3, 1854.

bad effects on the health of the men, employed in sewer works; both in London and in Paris, the average duration of life, of that class, was as great as that of any other labouring men, and larger than in many trades, producing only the luxuries of life. Dr. Parent Duchatelet gave excellent testimony on this subject.

If the principle of 'back-drainage' by pipes was adopted, there would be, on an average, five times the number of sewers required, as by the system, of each house communicating independently with the one main sewer, and there would be a proportionately increased liability to stoppage, and with not only inconvenience to one house, but also to all the others combined with it.

It was not fair to institute a comparison, between the expense of laying down a series of pipe drains, incapable of carrying away both the surface water and the house drainage, and that of the cost of a good brick sewer, of capacity to receive and convey away all that might be led to it, and not liable to be stopped up by deposit.[1]

Mr. Bazalgette had used pottery-pipes, to some considerable extent, for house drains, and in courts and small streets, and when of good quality, of adequate dimensions, well laid, and opening independently into brick sewers, they might be efficiently employed, but he complained of the too indiscriminate use, or abuse of them, and of the attempt to employ them in situations, for which they were not fitted, or for which they had not been intended.

Mr. Haywood explained, that he had been careful, in all the pipe sewers he had constructed, to provide shafts at their heads, so as to have the power of flushing them periodically, with a considerable body of water. For the sake of experiment, this periodical flushing of the pipe sewers, had been discontinued for some time, and although most of them were laid with excellent gradients, some had accumulated deposit varying from 1 inch to 3 inches in depth, measured at their outlets; but as to the condition of the pipes higher up, it was impossible to say

[1] Vide "Report to the Metropolitan Commission of Sewers, upon the Drainage and Water Supply of Rugby, Sandgate, Tottenham, St. Thomas-Exeter, and Barnard Castle." By J. W. Bazalgette. 8vo. London, February, 1854.

anything, as no examination of them could be made without considerable expense and inconvenience in opening the streets.

Mr. DUNCAN gave an instance, at Kilburn, where there had been a line of pipe sewer laid, at some considerable depth; it was soon found to be stopped up, and on digging down, it was discovered, that the clay had been washed in through a comparatively small hole, and had filled a length of nearly 100 yards, that several pipes were split, or crushed, and in fact, that it was necessary to lay the whole again, with better pipes. It appeared, that the unequal ramming of the clay, into the trench, had been prejudicial, or that slips of the earth had occurred, after the work had been apparently completed.

Mr. LOVICK, in reference to the failure of the pipes at Kilburn, said, he considered it due to the Engineer who advised the use of pipes in that situation, to state, that they were crushed by the falling of the earth upon them, in consequence of the giving way of the sides of the trench, arising from the improper removal of the timber shores. It should also be stated, that those which had failed were, for the most part, condemned and rejected pipes, of 15 inches diameter, very many being cracked before they were laid down, and they were crushed at the time of laying; these remarks applied to the whole length, of nearly 1000 feet of pipe-sewer, mentioned by Mr. Duncan.

Mr. DUNCAN said the whole line of sewer had failed, and was then being reconstructed, at a very considerable expense. It was not correct to state, that all the pipes were defective; some of those, of 15 inches diameter, were of indifferent quality and were previously cracked; they were laid at a depth of 16 feet from the surface, and could not bear the weight of earth upon them; the other pipes, 9 inches and 12 inches diameter, were sound when laid. His objection was, not to the use of pipe drains, in proper situations, nor to the material of which they were manufactured, but to the system of constructing main sewers of such dimensions, as precluded the possibility of men passing up them, to clear away deposit, to make good the junctions for the houses, and to do general repairs, which would inevitably be required in time, in all sewers; when that period arrived, if pipes were used for the main sewers, the expense would be terrific for the ratepayers.

Mr. TOULMIN SMITH said he had heard the Paper, and had

listened to the discussion with attention, as he had taken great interest in the sanitary part of the question; and although not an Engineer, he believed that he understood enough of the subject, to enable him to demonstrate some fallacies, which had been already widely promulgated, and which, unless they were contradicted, might be very prejudicial to the community. In doing this, it would be necessary to mention the General Board of Health, and to take exception to the proceedings of that body; but he would confine himself, carefully, to the statements and doctrines contained in the published Reports of that Board, and he would beg his remarks might be so understood.

He thought, that in order to examine fully into the question of the drainage of towns, it was necessary to do more than merely discuss the respective merits of pipe drains, or of brick sewers. The means to be employed were subordinate to the general plan; and the public, whose welfare was deeply concerned, had a right to understand the principles, forming the basis of the system pursued; particularly when a Government Board reserved to itself the power of (*de facto*) rejecting all plans, which did not appear to be in accordance with the published rules, or were disapproved by the examining Engineers, appointed by that Board; for this was the actual result of the power, under the Public Health Act, of refusing consent to borrow money, for the execution of works, unless the report of the Inspecting Officer was favourable.

In the Paper which had been read, certain propositions had been laid down; and it was, he conceived, the object of the Meeting to examine into their soundness, or their fallaciousness. It would not be sufficient that they were dogmatically dictated in Blue Books: if they were sound, their foundations should be clearly defined and understood; but if unsound, it became highly important to ascertain on what data and on whose authority they had been founded and were promulgated.

These propositions were—

1st. It was not necessary, that a system of town drainage should provide for carrying off flood-water, or urban rain-fall.

2nd. It was equally unnecessary to construct sewers large enough for men to traverse; and small-sized drains were in all cases preferable.

3rd. All drains should be constructed of materials impervious to water.

Now Mr. Toulmin Smith differed entirely from all these propositions; and he disputed both their theoretical and practical accuracy. As to the first, the Author admitted, that the original object of sewers had been, not to convey away house-drainage, which was a modern refinement on the system, but to carry off the surface-water, which it was now proposed to exclude. It must not be forgotten, that Nature, who sent the rain-fall, also provided for its passing off by the natural inclination of the surface. Much had been said about preserving the natural outfall; but wherever man interfered with the natural drainage, (and it was impossible for him to avoid it, in grouping together houses in towns, and arranging altered levels of streets,) some artificial system, superficial, or subterranean, must be provided. If the latter, then either the house drainage must be combined with it, or two sets of sewers must be constructed to maintain the separation, at a greatly-increased cost, as well as at the chance of greater annoyance from the increased risk of stoppage of a double set of drains, one set of which would be dry, when there was no rain, and the other would, generally, have only such a quantity of water passing through it as would scarcely suffice to keep the contents in a fluid state, and be wholly inadequate to scour the drains out, as was effectually done in ordinary sewers, whenever a heavy fall of rain occurred. The Paper protested altogether against the use of gully-holes, although it might have been imagined, that the most superficial investigation would have demonstrated the fallacy of such a proposition. It would only be requisite to quote one instance, in support of the necessity for them; he alluded to the case of Highgate Hill, where, in consequence of the steep declivity, the rain-flood rushed over the surface, accumulating in its passage, until it formerly inundated and committed serious damage in the low grounds; but by the construction of drains, and the insertion of a large number of gully-grates, (in one part as many as nineteen, in a distance of three, or four hundred yards,) the water was effectually conveyed away without difficulty.

As to the second proposition; it must be obvious, that a body of water unnecessarily expanded in a thin sheet, over a wide surface, was retarded by the extra friction, and had a tendency,

with the loss of velocity, to deposit the matters held in suspension; and also that, if the channel was contracted, the friction was diminished, the course of the fluid became clearer and more rapid, and the tendency to deposit was diminished. It was, at the same time, equally obvious, that whether this contracted watercourse was 12 inches diameter, or 5 feet high and 12 inches wide, (the form of the bottom remaining identical in either case,) there could not be any difference in the facility for the flow of water, or in the friction over the bottom; but the latter form (the brick sewer) possessed the manifest advantage of permitting free access for inspection and repair, whilst the former, (the pipe drain,) had the evident disadvantage of being liable to be choked by deposit, and of its being necessary to open the ground to discover the position of the stoppage. Hence, as also in every case of laying on new junctions with houses, there arose great breakage of pipes, as well as general dislocation of the system. It was admitted, that pipe drains, in order to insure efficiency, required to be laid with the greatest nicety and accuracy,—a thing practically impossible. It was further admitted that, above a comparatively small size, brick sewers were cheaper than pipe drains. If this were so, common prudence dictated the use of such subterranean conduits as might be cleansed and repaired, without causing annoyance to the public, and at an infinitely less cost, than by digging down to and replacing broken pipes. Besides, with the larger sewers, all possible contingencies of rain-fall, &c., were provided for, without the liability to such instances of false economy as had been recently exhibited at Holloway, where a pipe drain of 12 inches diameter, which had been laid only about four years previously, was now being taken up and replaced by a brick sewer of 4 feet 3 inches diameter.[1] This was not only a public annoy-

---

[1] The following letter was given as the authority for the statement:—

"*Sewers' Office, Great Alie-street, Whitechapel,*
"SIR, *13th December*, 1852.

"During the discussion at the Institution of Civil Engineers, reference was made by you to the 12-inch pipe sewer in Holloway-road. The statement was correct; but such pipe was laid down by the Engineer previously having charge of the Finsbury Division. I am, as you perceive, taking up the 12-inch pipe, and placing, in lieu thereof, a circular sewer 4 feet 3 inches in diameter; and even this will be full in heavy storms, as

ance, but an unjustifiable waste of money, inasmuch as it resulted from the dictatorial enforcing of certain dogmas, which were put forth, in defiance of scientific investigation, or practical facts, and entailed on the public heavy and uncalled-for cost.

As to the third proposition; it appeared to be lost sight of, that, for the sake of health, it was as requisite to drain the subsoil of the site of houses, as it was to convey away the artificial foul house-water. Now for the former purpose, glazed, or vitrified pipes were entirely unfitted, unless the joints were left open, when the fœtid contents would ooze out. Therefore, if they were used, the keeping dry of the cellars, or basements could not be promoted, although in a sanitary point of view that was of the utmost importance. The subsoil moisture would then have a tendency to saturate the ground, would undermine the pipe drains, and allow them to sink and be fractured; and, as another incidental result, the sewage matter would exude, and add to the causes of disease-bearing miasma. Such was not the case, where properly constructed pervious brick sewers were used, with the inverts laid in cement. These not only conveyed away the sewage, but they drained and kept dry the soil, through which they passed, rendering the lower portions of all the adjoining houses healthy and habitable, and the neighbourhood less likely to be flooded by sudden rains falling on a saturated soil.

The other practical objections, that might be urged against the newly introduced system of pipe drainage, were far too

---

of late. In taking up the pipes in question, I found three of them broken. In almost every case where we have to put in junctions to these pipe-sewers, the same is the result. On a recent occasion, in Mile End, in an 18-inch pipe, laid down about four years since, under the supervision of another officer, in every opening that has been made to the same (which are many) the pipes are found split down the centre. My object in writing you is that you may set the matter right at the Institute. Many may consider, that the pipe was laid down by me; whereas this sort of thing is in opposition to my practice, and to that of my respected father, who was Surveyor to these districts many years, and who has constructed more brick sewers than any person in the kingdom.

"I remain,

"Yours respectfully,

"GEORGE ROE,

"*Engineer for Finsbury Division, Tower Hamlets, Poplar, and Blackwall.*"

"*Toulmin Smith, Esq.*

numerous to be descanted upon, within the limits of a discussion at the Institution; especially as there were other points of equal importance to be noticed. One of these was, why had the public submitted without inquiry, and almost without remonstrance, to the dictation of the General Board of Health? The reply would be best given in the words of a petition from the local Board of Health of Swaffham, Norfolk, to the House of Commons, in 1851, wherein it was stated, "That the General Board of Health has the power of refusing to any Local Board the privilege of borrowing money; thus having a veto on every act of any Local Board, unless the rules and regulations laid down by the General Board are fully carried out." This allegation was confirmed by the text of the Public Health Act, and also by the statements in all the blue-books published, at the public expense, by the General Board of Health. Thus it was expressly declared (Report 1849, p. 72) that "works should be carried out, upon approved plans by the Local Surveyor, under the Superintendence of the Inspector;" and again, new works must be "under the Superintendence of the Inspector;" and again, it was declared, that the Board of Health "adopts, as a principle, to sanction the mortgage of rates, and the distribution of charges, only on conditions such as the following:—

"1st. That plans and estimates have been prepared in detail, and submitted for examination to an Inspector.

"*a* And upon his Report found to be deserving of approval, &c.

"2ndly. That the works shall be executed upon contracts, on the following conditions:—

"*a* That before they are covered up, or put in operation, they shall be examined by the Inspector.

"*b* That they shall be further examined by him when in action, and be certified by him."

And the characteristic tendencies of the same Board were well shown, in the same Report, when they "rely on compulsory powers being given, adequate to the enforcement" of their schemes; and represent to Parliament that the "Board should be entrusted with the power of prosecuting, for the neglect of its regulations."

The foreign system of centralization was gradually pervading

all branches of the administration, and producing the most pernicious effects; the opposition offered by the Admiralty and the Railway Department to many useful enterprises, was notorious, and would ere long no doubt be noticed publicly; but the General Board of Health, profiting by an unaccountable supineness on the part of the profession, had already succeeded in reducing the Engineers,—to the triumphs of whose enterprise and skill England owed so much of her wealth and prosperity,—to the position of mere clerks of works, mere subordinates to the obedient retailers of its own procrustean dogmas and bureaucratic crotchets. It required, that its own express sanction should be given to every system of drainage adopted in any town that came under its jurisdiction; thus interfering, altogether, with the independence of inquiry, enterprise, and action both of Engineers and of those who called in their assistance. The immediate, necessary, and fatal effect of this circumstance, upon the realizing of just views, or real progress, in the question of the "Drainage of Towns," was very obvious. Mr. Toulmin Smith could not but call attention, as immediately illustrative of the subject, to the well-known fact of how, one after the other, different schemes, in reference to the drainage of towns, had been promulgated by the same authority; each in its turn put forth with equal positiveness and pretences to infallibility, and then, by the same authority, discarded and denounced, after great and useless expense had been incurred in many places. Thus it had been with the system of flushing, with that of contour lines, and with that of 5 feet-to-the-mile surveys.

A great deal had been said, of the success of the pipe system at Tottenham; now with respect to that place, it should be known, that only about two hundred houses were connected with the pipe sewers, and that the works were still proceeding; so that neither from the small number of houses, nor from the length of time the works had been in action, could any correct result be assumed.

From the considerations which had been brought forward, these general conclusions were to be drawn:—

(1) That tubular drains were useful for house-drainage, and for short distances, under special circumstances,—but that glazed, or vitrified pipes should not be used, unless where actually within walls:

(2) That they were not usefully applicable, as part of any system of arterial drainage:

(3) That drains should be made of such size as to enable them to meet all probable contingencies; whether of increased town-drainage, or of flood-waters and rainfall;—while their form should be such, that a clear and rapid flow of the ordinary run should be insured:

(4) But the most essential point, for securing efficient town-drainage, and promoting sanitary and other improvements, was, that Engineers and those who engaged their services, should maintain themselves independent of the dictation of Government Boards, and should be guided, as in other cases, by the accepted opinions of acknowledged competent authorities, and by the practical results obtained and recorded, as the fruit of the most careful inquiry, enlarged experience, and unfettered skill, of the ablest professional men of self-earned reputation.

Mr. Holland said, that after the disparaging observations just made, it might seem to require some courage to avow himself an advocate of pipe sewers, were it not for the remarkable circumstance, that the manufacture of these pipes, which, until within a few years, had scarcely been heard of, had grown into such an important branch of national industry, that one manufacturer alone produced 18,000 yards a week, and that was of course but a small portion of the whole quantity made. In the face of such a fact, it would be as useless to attempt to persuade the public, that pipe sewerage was a failure, as to make a Manchester-man believe, that calico was an unfit article for clothing.

It had been remarked, that all were agreed as to the utility of pipe sewers; the difference of opinion then was, as to the extent to which they should be used, or the manner of their application. Mr. Holland was glad to hear that great admission, but still, all, did not appear to be agreed; for by some it was contended, that though pipe sewers were cheaper to construct, they were dearer to keep in order, although no proof of the correctness of that assertion had been offered.

It had been said, that it was most desirable to attain some form and material for the construction of sewers which should not require to be opened twice in a year. He trusted it was

not meant to assert, that this was anything like a fair representation of the case, with respect to pipe sewers. (It was here explained, that no statement had been made to the effect, that pipe sewers generally required to be opened twice in a year, but that some of them had required to be so opened.)

Mr. Holland contended, that the statement, as quoted in the authorised reports of the proceedings, was calculated to produce such an impression, and that impression was contrary to fact. In Manchester, pipe drains had been extensively and satisfactorily used for several years. In the City of London, there had been only three stoppages, in about one hundred pipes, during eighteen months; and at Richmond, on inquiries made at one hundred houses indiscriminately, no failures were met with, nor any stoppage, that had not been cleared away by water alone. But even supposing that pipes were expensive to keep in order, which however had not been proved, the question was, whether that expense was so great, as to counterbalance the economy of the original construction. The town of Rugby had been drained with pipes, at a cost of £3,600, now if the same length of brick sewers had been made, according to the scale, for general adoption, given by the former surveyor of the City Sewers' Commission, the cost would have been £15,000, or £11,400 more than the actual cost. The interest of the difference (£570) would pay for replacing nearly one-sixth of the pipes every year, and nothing approaching to such a proportion of repairs could possibly be required.[1]

In spite of the violent opposition to which the new system had been exposed, it was making rapid progress, and many of those who had opposed it, and appeared still to oppose it, were now using certain portions of the system. This improvement had been, like every other great innovation, at first disregarded, and despised,—next abused as quackery,—and at length gradually adopted, whilst the proposers were abused; eventually it would be discovered that the invention was a good one, and

---

[1] The state of the drainage of those parts of the Metropolis and of numerous towns, where tubular pipe sewers have been used, is shown in the "Copies of Reports and Communications in reference to the Drainage of the Metropolis, &c.," Parliamentary Paper, folio, 11 April, 1854, and the Reports of Mr. Bazalgette on Tubular Pipe Drains and Sewers, &c., Parliamentary Paper, folio, 24 June, 1853.—Editor.

that its proposers should have been praised and its opponents censured.

Mr. A. Francis said, that unglazed earthenware, might, he thought, be as advantageously used for pipe drains as the most impervious glazed pipes; besides, the cost of the latter was about double that of the former. He exhibited specimens of red unglazed pipes, found at Chester, and which were believed, from the inscription, to have been laid by the 12th Roman Legion. The Babylonians also employed unglazed ware for tubular drains.

Mr. Joseph Cliff, through the Secretary, said he had, for some time, been making considerable quantities of large-sized pipes, or tubes, at the Wortley Fire-brick Works, for the drainage of the towns in the district. The pipes were generally egg, or oval-shaped, and the largest sizes were 20 inches by 15 inches, 25 inches by 18 inches, and 30 inches by 21 inches. Of this latter size, nearly 7000 yards had been already laid down, in the streets of Leeds, since the drainage commenced. In consequence of a doubt, as to the advisability of the system of pipe drainage, men had been sent up the sewers, to examine them and to report upon their condition. They had been exposed, in many parts, to the heavy traffic of the streets, and the late heavy rains having caused subsidence of the ground in the trenches, and in several instances filled the tubes themselves full of water, they had been as severely tried as it seemed probable they ever could be. After a minute investigation, the pipes were found sound and good, and not one single failure was discovered in the whole line, which had the appearance of being self-cleansing.

These pipes were made of a strong metallic fire-clay, which by resisting an intense heat in the kiln, allowed the inner and outer surfaces to be vitrified and to receive a good glaze, still retaining their shape and not splitting, or cracking in cooling. They were made about 2¼ inches in thickness, and if it was found, by experience, that greater strength was required, there could be no difficulty in making them thicker. Those used in Leeds, were all socket-pipes; while those laid in Manchester and that neighbourhood, had only plain butt-joints. It appeared, that many of the gentlemen, taking part in the discussion, were not aware of pipes of that size and thickness being made, and

their objections to pipe drainage were founded, to some extent, on the size, nature and thickness, of the London-made pipes, with which they were alone familiar. It was impossible to make the London pipes of the sizes and thickness mentioned; the quality of the clay forbidding it, and appearing to involve the necessity of their being made thin and merely as pottery-ware, or pot-pipes, and therefore possessing the ordinary characteristic of pottery-ware,—a liability to snap, or break, by sudden concussion, or under heavy pressure. Large sizes, of the necessary strength, could not, therefore, be made from London clay. In the Leeds district, however, there was not any difficulty in making pipes of almost any size, and strong enough to bear any external pressure. The pipes, he had mentioned, were made under pressure, by Spencer's machine, the socket being made at the same time, and not being put on afterwards as was often the case. If required, still larger pipes could be made, up to 36 inches, and of any requisite thickness. Mr. H. Wrigg had used large quantities of these pipes, at Preston; he preferred having them of circular section, giving to them the dimensions of 1-8th inch in thickness to each inch of the diameter; thus a pipe 24 inches diameter would be 3 inches thick.

It might be considered as a fact, that oval pipes could be made even up as high as 3 feet by 2 feet 4 inches, and of proportionate thickness, without difficulty.

Mr. Cawley stated, through the Secretary, that at Manchester, the substitution of pipe drains made of fire-clay, for all sewers of less than 2 feet diameter, had been successful, and he believed, that few breakages had occurred, except in cases where the pipes had not been sufficiently covered, and the concussions of the wheels of heavily-loaded carts had affected them. He had used earthenware pipes, of 12 inches and 20 inches diameter, for conveying pure water to a reservoir, laying them at depths varying from 3 feet to 6 feet, and without any case of breakage. It was true, that the pipes in Manchester were, for the most part, laid in hard gravel, or strong clay, and he could not conceive why any fracture should occur, if the pipes were well bedded, and the earth was well rammed around and above them. If there was unequal pressure, fracture must ensue.

He had received from Mr. John Francis, the Surveyor of the Paving and Sewering Department of the City of Manchester, the following reply to questions proposed to him, in consequence of reports as to the state of the pipe drains at Manchester:—

"The main, or street drains, are laid at various depths, from 9 feet to 30 feet; the passage and branch drains at all depths, from 2 feet to 10 feet.

"The ordinary inclination, for main drains, is half an inch per yard, but a few are laid at a quarter of an inch per yard. I do not remember any with less than that inclination. Branch, or house drains, have an inclination of 1 inch per yard and more, according to circumstances.

"The largest size we have used is 25 inches by 18 inches, and the maximum size, at which tubes are likely to be preferable to brickwork is, I think, 3 feet by 2 feet.

"The largest area drained into a tubular sewer, is about 50 acres;—but the whole area is not yet drained, and the tube, at its outlet, has never been half full. With respect to areas of drainage, my experience is in accordance with the recent 'Minutes of Information of the General Board of Health' as to the sizes of sewers required. But in practice I have adhered to sizes in excess of any formula. I think this should be done for the smaller areas, and greater exactness be observed, as you approach the larger areas.

"I am now constructing an oval sewer 64 inches by 48 inches for a brook, having a drainage area of 550 acres, with an inclination of 1 in 300;—(commenced before I saw Mr. Roe's table and agreeing very closely with it.)

"The smallest tube I have used, for main drains, in small streets and passages, is 12 inches by 9 inches, and the smallest branch drain, for foul water, is 6 inches by 4 inches. There is a principle which appears to me inimical to the use of very small tubes for foul water, or water loaded with solid matter; viz. the ratio of the periphery to the transverse area, increases inversely to the size; therefore also the friction and liability to stoppage; other circumstances being similar.

"Our drains and sewers are intended to take off storm waters, and no case has come within my knowledge, where our tubes have appeared to be incapable of this duty.

"We have not had one case of breakage from pressure, where the tubes were laid 2 feet, or more, below the surface. The laying and packing well with earth is the main point. All decay in sewers arises (within my experience) more from the stream within, than from the pressure outside. Our soil here, both clay and gravel, is tunnelled for sewers, ordinarily, without timber, therefore, when the soil is laid compactly about the tube, the pressure upon it is next to nothing. We use no sockets to our oval tubes, for the drains, but have them to the round pipes, which form the vertical shafts, connecting the surface with the main drains. I am more satisfied, every day, with our rejection of the socket joint. I am not aware of any disadvantage from its absence, and I partly attribute, to that cause, our immunity from breakage. It is easy to see, that in pipes having sockets, carelessly laid, the said sockets become so many points of unequal pressure. We have had many cases of stoppage, at the upper extremities of our drains, which soon caused me to adopt universally a syphon trap to every grating; but upon the whole, and taking into consideration, that we were left to acquire our experience unaided,—I think our success, in the use of tubes, has been most signal,—and for minor sewers and drains, glazed fire-clay tubes are preferable to anything else."

Mr. J. Evans, through the Secretary, said that, as Borough Surveyor of Salford, he had paid considerable attention to the working of the pipe-drain system, and had given it a fair trial himself. He had not used any pipes of less dimensions than 6 inches by 4½ inches, nor larger than 12 inches by 9 inches, and those only for conveying the surface water from court-yards,—passages,—and streets, into the egg-shaped main sewers, which were built of brick-work, and varied in size from 42 inches high and 32 inches wide, down to 24 inches high by 18 inches wide. In fact, the Committee would not permit any earthenware pipes to be used for main sewers, as they had individually suffered, from having allowed them to be laid down on their private properties, in Manchester, where they found, that the trouble and expense of keeping them clear, and the difficulty of connecting branches into them, formed serious objections to their use. It was even broadly stated, by men who appeared to have experience, that the pipe-

drain system had been carried to an extent in Manchester, which would eventually cause serious inconvenience.

Mr. B. Baylis, through the Secretary, said the extensive system of egg-shaped brick sewers, varying from 3 feet 6 inches to 2 feet high, constructed under his direction at Chester, had proved thoroughly effective, and were found to be less costly, than any other system that could have been adopted. He had tried a few pipe drains in mews and back streets, but none of less than 12 inches diameter. In the course of the sewering operations, it had been necessary to take up several old pipe drains, 9 inches in diameter, in consequence of their proving ineffective and being choked up, although generally having good inclinations, and in all cases he had substituted larger pipes, or brick sewers, as being the cheapest at last.

From his experience, he believed earthenware pipes, if not less than 6 inches in diameter, to be well adapted for house-drains, but totally unfit for the main, or even the subsidiary sewers of a town of any importance, unless the inhabitants were prepared to submit to the expense, and the annoyance, of having them taken up once in three, or four years. The system of sewerage in Chester, had been in operation for some years, without there having been a single failure, or stoppage, since the completion of the work.

Mr. Plum said, if it was considered advisable, to go to such expense in the subsoil drainage of agricultural land, how much more important was it, to use such forms, capacities, and materials for the sewers, as should secure the perfect drainage of town areas, at the same time that the conveyance both of the surface-water, and of the house-sewage was provided for! He agreed in the disadvantages of the glazed pipe drains, because, being impervious, they could not aid in drainage, unless, as with common drain-tiles and pipes, the joints were left open, which in town drainage could not be permitted; it appeared, also, that the gradual deposit, in some cases, and the presence of extraneous substances, in other cases, were the causes of the stoppages in both pipe drains and brick sewers; it became then a grave question, whether the solid matters of house drainage should be permitted to pass, unchanged in their character, into the pipes, or the sewers, and whether the house drainage should be mingled at all with the surface-water; the latter might, in

all cases, be permitted to flow into the natural outlet,—the adjacent river, at the nearest points,—but the former should not be allowed to pollute streams, especially if the matter could, as was stated, be advantageously used for agricultural purposes. That part of the question was, in his opinion, the most important, and to that the attention of the Meeting should be devoted.

Mr. May said the broad question had not yet been adequately treated, and he apprehended the hesitation arose from an unwillingness to attack the doctrines which had been so authoritatively promulgated; as, however, he thought there should not be any scruple in publicly examining public questions, or the acts and opinions of public Boards, and it was the duty of Engineers to canvas this town-drainage question very freely, he ventured to direct attention to the general question.

It appeared to him, that one of the great errors committed had arisen from the apparent advocacy, by the Board of Health, of the schemes for the preservation of sewage refuse for ultimate use. Now it must be evident, that the primary consideration should be, as stated in the Paper, the best method "of the instant removal, from the vicinity of dwelling-houses, and from the sites of villages, towns and cities, of all refuse," foul-water and surface-water, accumulating among the habitations of man, in order to avoid those exhalations, which were known to be so prejudicial to health, and were admitted to be most frequently caused by sewer deposits. If the contents of the sewers could, ultimately, be beneficially employed for agricultural purposes, they should not be neglected; but he thought a very exaggerated value had been attached to that kind of manure; and, from all he could learn on the subject, he believed there were very few situations, where the attempts to combine sewage manure schemes, with the drainage of large towns, had been found practicable. In some small towns and villages the system might be successful, but they were exceptional cases, which could scarcely be used as arguments in favour of the adoption of the system, and the drainage of the Metropolis, or that of other large cities and towns, should not be tampered with for such purposes. It did not appear to be proved, that the method of having separate conduits for the surface-water and for the house-sewage was either the best, or the cheapest; inasmuch as

the opponents of the scheme asserted, that unless the occasional action of flushing by storm-water was permitted, gradual deposits occurred, and the pipe drains became choked; and no fair comparison of the relative expense of the two systems could be obtained, because the separate method had only been tried where old sewers previously existed, but which were now entirely devoted to surface-drainage, and the outlay was really only that of small pipes, of just sufficient area to carry away the house-sewage.

He took exception to the accuracy of the statement, in the Paper, as to the rate of mortality at the Portland Convict Establishment; if that statement was to be received as accurate, it would lead to the assumption of the extension of human life to one hundred and fifty, or two hundred years; and though the decrease of mortality, resulting from a general improvement of the sanitary condition of towns, might be admitted to the fullest extent, yet he could not credit such results as those given for Portland, and he thought great injury would arise from the promulgation of statements, which when analyzed, would be found to exhibit untenable inferences and impossible results.

Mr. R. Stephenson, M. P., V. P., said it had not been, originally, his intention to take part in the discussion, but so much had been said, that was either wide of the subject, or dictated by preconceived notions, to be supported at any rate, that he could not resist attempting to bring back the discussion to a useful track.

It had been said, that converts were rarely made by discussion;—that might be true, with respect to questions in which the passions became excited; but when, as should be the case, in considering all scientific questions, truth was the only object sought, he must submit, that honest statements of facts, must carry conviction with them, and would eventually produce effect; time might be required for consideration, before conviction was induced; but even if discussion only produced repetition of experiments, or more careful analyzation of known results, the end was fully answered and good must result. Now in such a question as the present, honest facts had an amount of weight, which mere unproved theoretical schemes never could possess; and it was admitted, by unquestionable practical authorities, that mere abstract principles did not hold good, in questions of

the sewerage of towns, where so many local circumstances and domestic occurrences interfered with the perfect working of even the best-designed general plan.

When he first joined the Commission of Sewers, he believed that he did understand the subject and could have designed any work of the kind, to the perfect satisfaction of the inhabitants; but he soon discovered, that his previous engineering experience, although it naturally aided him, did not suffice to enable him to take into immediate consideration all the numerous bewildering local circumstances and the domestic difficulties with which the subject was surrounded; and he must say, that he almost envied the self-confidence, whilst he was astonished at the daring of the Board of non-professional men, who had not hesitated to lay down definite rules, to meet all cases of this most indefinite branch of professional practice. When he attempted to procure information from the published reports and accepted data, he became still more confused, by the discrepancy of the various statements; so he resolved to examine personally and judge for himself, and the result was, the conviction that for certain localities, if pipe drains were sufficiently strong to resist fracture, and sufficiently large to avoid being choked up, they might be advantageously employed, to form the connexions of houses, courts, and other small localities, with the main sewers, which should be constructed of brick, of such dimensions as to admit of easy internal inspection, and repair, and be of such form, (except where the flow of water was, at all times, considerable,) that the radius of the curved bottom should be able to gather a small supply of water into a sectional area, affording the same hydraulic mean depth as in a pipe drain, of a diameter merely adapted to discharge the minimum flow. The removal of obstacles, or accumulations, from the main sewers, by manual labour, was not more dangerous, or noxious, than the ordinary employment of most working engineers, or of men engaged in the execution of constructive works; indeed there were numerous callings, rendered necessary by the present wants of society, which were much more injurious to health, and it only required proper attention to the ventilation of the sewers to provide against any accidents which were likely to occur. Besides, in comparing the sweeping of chimneys by boys and the cleansing of sewers by men, it must be remembered the former was com-

pulsory, under a bad system, and the latter was the voluntary act of free agents, and it was a mere exhibition of false sentiment, to put forward such an argument in favour of the introduction of pipe drainage.[1]

The best practical arrangement for any machine, was not, invariably, that which gave the most economical application of its power, but frequently that, which, with the due direction of its force, combined the greatest facility for its erection, for its being kept in order, and for its rapid and effective repair, in case of accident.

So with a system of drainage, the small pipe-drains might be efficient, if circumstances never changed and accidents never occurred; but the Reports to the Commissioners of Sewers, showed, in many instances, that notwithstanding every care, the most extraordinary articles found their way into the small conduits, and their entire failure ensued;[2] besides, that unless a heavy pressure of water was used, in conjunction with pipe-drains, stoppages would occur, and this pressure system, like a great influx of storm water, for the conveyance of which pipe-drains were not adapted, caused such an accumulation of back water, as flooded the basements of the houses. Scarcely a day passed, without there occurring complaints of flooding, during rain, or of stench during dry weather; and it was observed, that, in the majority of cases, the complaints proceeded from places where the system of combined back drainage had been

---

[1] It is stated by Dr. Parent Duchatelet, in his "Hygiène Publique," that "Les maladies, occasionées par le sejour dans les égouts, sont en petit nombre, une seule peut occasioner la mort, c'est l'asphyxie; les autres n'offrent pas de danger, il est même rare qu'elles acquierent un haut degré de gravité; ce sont l'opthalmie et les rheumatismes. On s'étonne qui les affections cutanées, que les ulcères aux jambes, ne soient pas comptées au nombre des maladies des égoutiers; non-seulement ces hommes n'y sont pas exposés, mais ils régardent l'eau des égouts comme un remède efficace contre les plaies, les ulcères et les éruptions chroniques."—Vide "Notice Historique," sur A. J. B. Parent Duchatelet. "Hygiène Publique," p. x. 8vo, Paris, 1836.—EDITOR.

[2] In the "Report of the General Surveyor of Works, under the Metropolitan Commissioners of Sewers," February, 1853, Mr. Bazalgette gives a detailed account of his examination of part of the pipe sewers laid in the metropolis. The Report comprises 122 cases, in various districts;—69 cases on the north side, and 53 cases on the south side of the Thames. He found, that in 113 instances the pipes contained deposit, varying in depth up to 7 inches, and 9 pipes were completely choked. In 23 cases, also, the pipes were either split, or broken.—EDITOR.

adopted. This was evidently an erroneous system, and, if ever pipe-drains were to be effectively used, it would be found imperative to have a distinct drain from each house, opening into a sewer, of sufficient dimensions to allow a man to pass along, to remove any accumulation, and to make any necessary repairs.

One of the supposed advantages of the pipe-drains, most prominently put forward by their advocates, was the greater amount of velocity, pronounced to be given to the flow of the contents of the pipes, by the cylindrical form and the smoothness of the interior. This he contended was a fallacious view, originating, probably, from some experiments, made when the pipes were running quite full and under some amount of pressure; but it was when they were about half full, that the observations should be made. Suppose for instance a pipe-drain 12 inches diameter, conveying only such a quantity of water as would half fill it, or make the stream 6 inches deep; and compare with it an egg-shaped brick sewer, whose bottom was formed to a radius of 6 inches, and whose sides widened gradually upwards, to a sufficient height for admitting a man to pass along. Now he contended, that, at similar inclinations, a stream of water also 6 inches deep would flow as freely in the brick sewer, as in the pipe-drain, and that when the stream filled up the entire area of the pipe-drain, the same quantity of water would pass more freely through the brick sewer, on account of there being less lateral friction, and there being a greater hydraulic mean depth. This was self-evident, and proved, that if a proper sectional form was adopted for the large sewers, a small quantity of water was as effective in them, as in pipe-drains, with the additional advantage of providing for sudden falls of rain, for accidental stoppages, and for the contents of the sewers being pounded up. Suppose the case of the south side of the Thames, where a part of the land was below low-water mark, and consequently, where there was a stoppage by the tide, of the discharge from the sewers, for sixteen hours out of every twenty-four hours; if the dimensions of the sewers were reduced by rule to just the sectional area calculated for the discharge, and no provision was made for the accumulation, during the period of inactivity, the contents of the pipe-drains must either be forced back, up into the cellars and basements,

or the pipe-drains must be burst. This would not occur, under ordinary circumstances, with proper-sized sewers; and, after careful consideration of the subject, Mr. Stephenson had arrived at the conviction, that there was danger and inconvenience, as well as extra cost, to be apprehended, from the indiscriminate and too general employment of pipe-drains; although they were applicable for special localities, and purposes, and he deprecated the publication of empirical rules and formulæ based on the assumed results of experiments, which had neither been well designed, nor carefully performed.

Mr. Bidder fully concurred in the observations just made; and he agreed with some few remarks in the Paper, particularly where the importance of permanency, in the construction of the sewers, was impressed, as an axiom; he was, however, convinced, that as great durability must not be expected from earthenware pipe-drains, as from sewers properly built of sound bricks; not the hollow, thin gimcracks, frequently proposed for imaginary cases. The ultimate expense of maintaining sewers, should be as much considered, as the first cost, and the drainage of a town could not be considered to be properly executed, if it was not an enduring, as well as an effective work. Instances had been given, of towns being well drained for a time; but when the stoppages once commenced, there was no telling to what extent the expense, or the public inconvenience, might extend. It was admitted, that a brick sewer of 36 inches diameter was, in some localities, as cheap as a pipe-drain of 20 inches diameter, and was not liable to the same casualties of fracture, or crushing. There could not be any hesitation as to which should be adopted by Engineers. It must be admitted, that permanency and durability should be the first consideration of an Engineer, in designing drainage work; and it was well known, that at inclinations, mentioned by the Author of the Paper, the abrading action of grit, on the bottom of pipes, or even on ordinary bricks, would soon wear them away, therefore thin pipes and hollow bricks were not to be used for main sewers, in great thoroughfares, or where tearing up the streets would be prejudicial to public convenience, or cause danger to the adjoining buildings.

The greater healthiness of a district, consequent on improved drainage, was no new discovery; but the result was exhibited

chiefly by the young lives; the benefit being almost inappreciable after sixty, or seventy years of age.

It was wrong to call in question the results of Mr. Roe's great experience, although opposed to the views of a public Board, as that Board had deemed the records of the observations of sufficient value, to warrant their paying a large sum for the possession of Mr. Roe's information, and had published them, for the benefit of the country.

He thought there had been some exaggeration in the statements with regard to the results obtained at Hitchen. If the stated quantity of water had really passed through pipes, of the area mentioned, the velocity must have been nearly twenty-five miles per hour, and it would have required a head of 20 feet, to force the water through the pipe-drains.

An unnecessary difficulty, of magnitude, had also been imposed upon Engineers, in consequence of the apparent determination of the General Board of Health, to render sewerage works subservient to their impracticable schemes, for the distribution of liquid manure, by pipes and mechanical means, over great extents of country, not merely adjacent to, but at considerable distances from the towns intended to be drained. As an instance in point, he might mention, the proposition, in 1849, to pump sewage water from London to Brentwood, a distance of 16¼ miles, to an altitude of 420 feet above Trinity H. W. level, through pipes of 7 inches diameter, for the purpose of irrigating an estate, and thence to continue the same sized pipes for upwards of 50 miles further, because it would "be easy to send the sewage on, as far as Colchester, or Ipswich, that being all down hill." It would be wasting the time of Engineers, to expatiate on the absurdity of schemes, betraying such entire ignorance of the effect of friction of fluids in pipes, but it was lamentable to see such documents proceed from public Boards having authority.

The plan now in course of trial at Leicester, under Mr. Wicksteed (M. Inst. C. E.), for separating the fertilizing matter, in a solid state, from the sewage water, by which the latter was deprived of its noxious properties, deserved to be mentioned with praise;[1] and if they were successful in producing at ade-

---

[1] In the Reports by Mr. Wicksteed "On the most advantageous mode of dealing with the Sewage Matter of the Metropolis," 8vo tract, London, 1854;

quate cost, a substance which could compete with ordinary manure, a great problem would be to some extent solved; although there would be great difference between operating upon the sewage of a town with a population of seventy thousand persons, and upon that of the Metropolis, with nearly three millions of inhabitants: still, for the south side of the Thames and all flat districts, where pumping must probably be had recourse to, under any circumstances of even moderate success, the system deserved attention.

Mr. Newlands said, reference had been made to his operations at Liverpool, in a manner calculated to convey an erroneous impression as to their nature and extent. In giving, from the Report to the Health Committee of Liverpool, the statement of works completed in December 1850,[1] there had been mentioned seventeen miles of brick sewers and only 487 yards of stoneware pipe sewers, and it was quite true, that those were the respective lengths of brick and pipe sewers, laid in the public

---

in "Observations upon the Nature, Properties, &c. of Solid Sewage Manure," 8vo tract, London, 1854; and "Preliminary Report upon the Sewerage, &c. of the Borough of Leicester," 8vo tract, London, 1850; it is stated, that Mr. Aikin found, by experiments on the London sewage water, that by the addition of about the three-thousandth part, by weight, of lime, the quantity of precipitate obtained was double that which had previously resulted from the simple precipitation of the solid matter, held mechanically in suspension, in the sewer-water; and, also, that the addition being much more valuable, as a fertilizer, the whole produce was thus rendered superior. In practice, on a large scale, these results were fully confirmed. The process of completely separating the solid matter from the water was very rapid; and the latter, being rendered pure and inodorous, was returned into the river, whilst the solid manure, after being subjected to the desiccating action of a centrifugal machine, was soon rendered fit to be packed up, and sent away for agricultural purposes.

Mr. Stothert, in an account of some experiments on his system of deodorizing sewage-water, states that "the deodorant employed (of which, however, the constituents are not described) is a powder composed of materials—abundant—readily obtainable—and inexpensive." "The process consists in the intermixture with the sewage of a comparatively minute quantity of powder,—itself composed of valuable fertilizing agents;—the effect is instantaneous." "Having been exposed to the influence of the deodorizing powder for a few minutes, the sewage matter, or cesspool contents, are rendered free from smell, and the ammonia and other gases are entirely fixed." "The water passes off from the precipitate as clear as crystal, and free from odour."—Editor.

[1] Vide "Report to the Health Committee of the Borough of Liverpool," by James Newlands, C.E., Borough Engineer, 1851.

streets up to that date; but on referring to page 32 of the Report it would be found, that what were there shown as main drains were in reality sewers, and without adverting to the difference in the nomenclature, adopted in the Report, where only the sewers in the streets, made at the public expense, were designated as sewers, the court and passage conduits being called main-drains, it had been stated, that the extent of pipe sewerage completed up to December 1850, was only 487 yards. Now these main drains from the houses were made at the expense of the owners of the property, and not out of the sewer-rate, and they consisted entirely of stoneware pipes from 9 inches to 12 inches diameter. He could not exactly state their aggregate length, but it considerably exceeded forty miles.

When a drain exceeded 12 inches in diameter, it was as cheap to use brick as stoneware, and he thought the former was also better and safer. In a place like Liverpool, where sewers had to be carried through streets only partially built, and where (there being no regulation as to the size, or description of houses, which might eventually be built,) the sewers had to be cut into, for connecting the branch drains, as the necessity for them arose. Stoneware pipes were very objectionable for main sewers, independently of the difficulty of obtaining them true in form, when of large size.

He perfectly concurred, in the importance of getting rid of the sewage with the utmost practicable rapidity, and in constructing the main sewers of such dimensions as to permit free access for inspecting and cleansing them, and for ascertaining the position of any stoppage in the tributary drains. For these tributaries the earthenware pipes were well adapted, if their diameter was large enough; he considered, that 6 inches was the minimum diameter to be used, except for branches; and it was essential, that each house should have its own distinct drain into the sewer. In the Report already alluded to, he had fully explained the system of 'house-draining' adopted at Liverpool, where the peculiar arrangement of the blocks of houses and of the streets, rendered the back-drainage for soil-water of easy attainment. He had also entered into a comparison of the system employed in Liverpool, with that recommended by the General Board of Health for universal

adoption, and it would be found, that the former plan worked uniformly well; but that if the latter was attempted to be used at Liverpool, any accidental stoppage, occurring in the receiving-pipe, could not be removed, without trespass on private property, and inconvenience to all the houses above the stoppage. The rain-water pipes from each house communicated with the house-drains, and aided in keeping them open, by flushing them during rainy weather; it must be evident how essential it was to avoid very small earthenware pipes, as their area should always be such, as to render them capable of conveying away heavy storms of rain, without flooding the premises.

The greater part of the town of Liverpool being situated on the sandstone, which was easily worked, the invert of the main sewers was generally cut in the rock, and brick arches turned over them. Where the ground was bad the sewers were entirely constructed of brick, and good hydraulic mortar. Near the Docks, where the sewers became elongated cesspools, for a certain period during each tide, precautions were taken by relief sewers, sluices, &c., to prevent the flooding of the basements. It was very important so to arrange the lines of sewers, as to intercept the drainage from the upper parts of the town, and not to allow it to pass into the sewers of the lower levels: this was a point to which he paid great attention. In general, he thought, that, as far as it at present extended, the system of drainage adopted at Liverpool might be stated to be quite successful.

Mr. Simpson, V.P., would not, at the end of so long a discussion, enter upon the consideration of many points which still admitted of much argument; he must, however, from long experience, warn the advocates of small sewers, with sharp gradients and a rapid flow of water, that the abrasion of the grit debris, &c., on the bottoms, would soon cut deep into the material, and therefore that earthen pipes, and thin hollow bricks were inapplicable for permanent works. The velocity of 7 feet per second, and the gradient of 1 in 60 mentioned as requisite, or desirable, for the passage of sewage through pipe-sewers, were objectionable for many reasons, and were generally unattainable in towns; and wherever the road sweepings entered into the drains, the abrasion would be found very

destructive, particularly with such a velocity as had been just mentioned.[1]

The selection of the outfall, although generally pointed out by nature, required very careful consideration, and many of the plans for town drainage had failed, in consequence of inattention to that point; in fact, local circumstances must, in all cases, guide the Engineer in the general outline, and the details of application, of any plan of drainage, as also in the nature of the materials to be employed in the construction of the sewers.

He could not agree with the proposed system, of constructing sewers, for part of the Metropolis, at such levels, with respect to the natural outfall, that it would be necessary to pump up the rain water, as well as the sewage. The examples of Holland and of the Fen districts of England, had been quoted as authorities; but, he contended, the circumstances were not analogous; in those agricultural districts the dykes formed large reservoirs, whence the rain-fall was pumped at a slow rate, probably about 1 inch per week; what would be the state of a town, where as much as 1 inch of rain per day had fallen, for several days consecutively? The amount of mechanical power requisite to lift that quantity of rain-fall, independent of the ordinary sewage, was very apparent, and the consequences to be anticipated from the floodings of the low parts of towns, were as evident, as the cost of providing and maintaining the pumping power; besides, the risk of flooding being so great, there must be a large surplus power, or duplicate machines, to guard against accidents, which might, otherwise, arrest the whole system.

It was sufficiently obvious, to persons acquainted with the subject, that some spot in the river Thames, below Blackwall, was the most proper position for the outfall of the London sewers; and with an ebb of tide of 15 feet in that part of the river, he contended, that the plans should not involve the necessity of employing artificial means for raising the rain-water and sewage. In cities and towns situated near the sea, or on the banks of rivers, where the rise and fall of tide was below 5 feet, the adoption of mechanical power, to pass off the

[1] The "Preliminary Report upon the Sewerage, &c., of the Borough of Leicester, by T. Wicksteed, C.E.," 8vo tract, London, 1850, page 17, &c., contains some useful remarks as to the velocity of fluids in pipes and sewers, and the dimensions to be given to the latter.—Editor.

sewage, would be justifiable, and in many cases a matter of necessity; but even then the judicious course would be, to divert the bulk of the rain-fall and storm-waters, at high levels, by means of the surface channels, or of separate catch-water drains.

He agreed, that no system should be condemned as entirely unworthy of trial; and in the case of the pipe-drains, there were localities in which they might be very advantageously employed; the great error was the indiscriminate application of the system, to places for which pipe-sewers were unsuited.

He had used with great success, a length of one mile of iron pipe, 2 feet diameter, for a sewer, in a district where the foundation was so bad and liable to move, that he should not have had any confidence in the duration of a brick sewer, and still less in that of earthenware pipes. The line of iron pipe had been down for sixteen years, without any stoppage, but he did not believe the result would have been the same with an earthen pipe-drain.

He believed the power of internal inspection of all sewers, was indispensable, and it would be found, but too soon, how great a mistake had been made, in using small pipe drains instead of accessible sewers, in great thoroughfares, where the public traffic, already seriously inconvenienced, by the lifting of the pavements, for the unavoidable repairs to the gas and water pipes already laid.

Mr. Gibbs said, his experience in drainage, which extended over thirty years, induced the conviction, that no Engineer, nor Board of Commissioners, could lay down any special principle for drainage works, which should be of universal application; each work, and even each part of the detail, must be judged of separately, with respect to the nature of the soil, the surface water-shed, the situation of the houses, and above all the density of the population.

No system could be perfect, which did not comprise, house-, surface-, and rain-fall drainage. It appeared, that the errors, promulgated by the Board of Health, in their hydraulic dicta, arose principally from their having adopted isolated experiments, which fitted their previously-expressed opinions.

One of the most evident of these erroneous data, was, that new inlets might be made into a pipe, without increasing the

sectional area of the vein; this, on the face of the assertion, was incorrect calculation and reasoning; velocity of course increased, as new accessions of water were applied; but velocity did not increase to an amount equivalent to the new accession of water, otherwise a pipe would never arrive at its maximum capacity of flow, nor would a river ever rise above its banks.

The mistake originated in the observations of the surface level of the water, between the minimum, or maximum velocity, not having been carefully made; the curvature of the surface of the water between these two points, constituting, in fact, the inclined plane of greatest velocity, and every accession of new sources of supply must alter this curvature, and the angle of the inclined plane, until the ultimate capacity of the conduit was arrived at.

These considerations were not new; it had always been known, that accessions of water did not increase the sectional area of water, in a ratio equivalent to the body of water admitted.

Frisi in 1762 [1] discussed this subject in a most learned and methodical manner, and his observations obtained great respect, even at this day.

The Board of Health recommended,[2] that the dung in slaughter-houses, garbage and other filth, should be passed down the pipe sewers. It was surprising, that rational and thinking men should have devised instructions of this character; —first to recommend the reduction of the size of the sewers, to their minimum dimensions, even to an extent which rendered their efficiency most questionable, and then, that materials be sent down them, which must reduce the fluidity of the water, and thereby lessen the velocity in a corresponding ratio.

Mr. Newton said, he was well acquainted with the town of Hitchin, and had carefully examined the drainage works executed there, under the system recommended by the Board of Health. Without entering into details, which were fully understood by all around him, he would state his conviction, that glazed earthenware pipes were not applicable for the main sewers, even of small towns, and much less for large cities;

---

[1] Vide "Traité des Rivières et Torrens;" par R. P. Frisi. 4to. Paris. 1774.

[2] Vide "Minutes of Information. General Board of Health Report." 1852, page 122.

although they might be used for house drains and branch conduits, where there was a good inclination. The glazed surface and impervious substance of the pipes were both objectionable, as the absorption and conveying away of the moisture from the earth was precluded; the result was, that the ground around became saturated with water, like a morass, the houses became damp, and the pipes were fractured, by the superimposed weight, and the subsidence of the mud in which they were imbedded. Such was not the case, where brick sewers were constructed, as they permitted a certain amount of absorption of moisture, and with them, there was not the annoyance of being obliged to dig down to them, in case of a stoppage occurring, as was constantly the case with pipe drains.

The SECRETARY, by permission, read the following extracts from communications, which had been examined by the Council:—

Extract from a letter from Mr. JOHN ROE (Assoc. Inst. C. E.), dated December 3, 1852:—

"I have received a letter, in which the writer says, that Mr. Rawlinson stated, 'that he had drained a town in Herefordshire, area 1500 acres, the outlet pipe being 20 inches in diameter, which he considered ample; but that, had he followed the rules laid down in Mr. Roe's table of outlets, it should have been 60 inches.'

"Were it not, that the subject is of the greatest importance to the public at large, I might take no notice of the comparison with the table, which I furnished to the General Board of Health, at their request;—that table being formed from repeated observations, during a period of twenty years, I can conscientiously and safely leave it to the test of time.

"That differently formed localities will require different applications, I have taken care to point out, in the notes I sent with the table; but when a theoretical opinion, differing so widely from observed facts, is not only put forth, but acted upon, I feel it right to say a few words on the subject.

"To render Mr. Rawlinson's theory a safe one, in practice, there should not be more than about 2 cube feet of water, per minute, come from an acre of the surface of a town, during a rain-fall of 1 inch in the hour, which fall produces rather more than 60 cube feet per minute per acre.

"On the other hand, I have observed 25 cube feet of water, per minute, per acre, reach the sewers from an inch fall of rain in the hour, from a surface, where the houses have much garden ground attached, and in another case, where the houses were nearer together, 33 cube feet, per acre, per minute.

"To pass the latter quantity of water through Mr. Rawlinson's 20-inch pipe, there must of necessity be a velocity of current exceeding 4 miles per minute, or 240 miles per hour: and if more than a fall of 1 inch per hour be expected, the velocity will need to be increased accordingly.

"That greater falls of rain do take place, and that not unfrequently, is a well-known fact. I have known ten instances of the kind, during the period of my observations, in the Holborn and Finsbury sewers.

"Mr. Rawlinson, in his report on Birmingham, gives an instance of a fall of rain of nearly 2 inches, in little more than half an hour; and a main sewer was shown to Mr. Rawlinson, on his visit, which a rain-fall had filled, a short time before, to within 3 inches of the roof; the area draining to it not exceeding 700 acres; yet the transverse section of that sewer had an area very nearly eight times larger than Mr. Rawlinson's 20-inch pipe, which he thinks ample for the drainage of 1500 acres.

"Facts are stubborn things, and in this case, the facts I am acquainted with (and they are legion) tell a tale the very reverse of Mr. Rawlinson's theory.

"When the importance of the question is considered, it becomes the duty of every one to endeavour to throw light upon the subject, and I hope the discussion of this matter, at the Institution, will enable the Council to send forth a practical report of the discussion thereon, for the benefit of the kingdom at large."

Extract from the Annual Report of Mr. John Roe, surveyor to the Holborn and Finsbury sewers, January 29th, 1847:—

"Some have been led to the advocacy of drains, or small sewers, to be placed in streets, or roads, without discrimination.

"Others advocate two lines of small sewers, or pipes—one on each side of a street, to receive the drainage; but as two such small sewers would not carry off the surface drainage in all cases, other parties consider, that one line of sewer should be formed for the surface, and another for the house drainage.

"In practice this would be found unnecessary, as regards any advantage to the sewer-water for manure; and as regards expense, it would, besides causing an immediate extra outlay, entail a perpetual annoyance and charge.

"A fact that will serve to illustrate this, is that of the new sewer built in Hoxton Town. On each side of Hoxton there was a line of small sewers in front of the houses. The cleansing of these, and other small sewers, has cost, on an average, one shilling and threepence, per foot lineal, each time of cleansing. Taking fifteen such sewers, the average time of cleansing has been four years and a half, and reckoning the first cost of the two small sewers, with the cleansing, the cost, in about twenty years, would have amounted to the expense of constructing an efficient sewer.

"This Commission has caused a new sewer to be built, in Hoxton Town, which will require no repairs for more than a century. The saving to the public, therefore, by constructing an adequate sewer, and thereby doing away with the two inefficient ones, will be double the amount that the new sewer has cost.

"After many years' experience, your Surveyor begs to state, that except a sewer has an extraordinary inclination, or has a body of water passing along it, with a considerable velocity, deposit will accumulate. If a small sewer, or drain, be choked with filth, no water will wash it clear, but the deposit must be raised and removed by manual labour; but, if 2 feet, or 3 feet in depth of deposit, is accumulated in a sewer large enough for a man to pass through (your new sewers ranging from 3 feet 6 inches to 5 feet in height, in the streets), such deposit could be washed away (by flushing) in the manner adopted in your own sewers,[1] where, for five years, all the foul deposit found in the sewers, where a man can work, has been washed away, although varying in depth from 9 inches to 4 feet.

"There will be few localities, whose outlets for drainage will be so situated as to afford, in every instance, such an inclination, or fall, to the sewers, as would enable occasional rains to clear them from deposit, and the water from the common house drainage would prove of little use for such purpose, unless dammed up for flushing, and the cost to supply water sufficient

[1] Vide Minutes of Proceedings Inst. C. E., Session 1842, vol. ii., page 132.

to keep a constant stream (as has been suggested in some cases), would soon amount to more than the expense of a proper-sized sewer, and the keeping it flushed in the ordinary way.

"In August last, the Surveyor had occasion to report, that 4 inches in depth of rain had fallen in one hour, on the first of that month; a circumstance that cannot be too extensively known, at a time when much sewer work is likely to be executed in this country; for having once experienced such a fall of rain, it is right to expect and provide for the like occurrence in future."

EXTRACT from a list of recorded casualties which have occurred to pipe drains in and near the metropolis:—

"George-row, Bermondsey.—Iron pipes substituted for the earthenware drains.

"Compton-street, St. Luke's.—The earthenware pipes 6 inches diameter had been taken up, and a brick sewer built.

"Rye-lane, Peckham.—Pipe drains 18 inches diameter failed, and the repairs cost £200.

"Camberwell Grove.—Pipe drains 12 inches diameter failed, and the repairs cost nearly £70.

"Orme-square, Bayswater.—The repair of the pipe drains cost about £50.

"King-street, Chelsea.—The repair of the pipe drains cost about £42.

"New Church-street, Edgeware-road.—The repair of the pipe drains cost about £14.

"Urinal in Covent Garden.—Stoppages cost about £12.

"Little Pulteney-street.—Stoppages cost about £25.

"Cherry Tree-alley.—Stoppages cost about £14.

"Elliott's-row.—Stoppages cost about £8.

"Holloway-road.—Stoppages cost about £7.

"Vine-street, Westminster.—Stoppages cost about £6.

"Hayes' Mews, Berkeley-square.—Stoppages cost about £25.

"Brunswick-street, Stamford-street.—Stoppages cost about £84.

"Pheasant-court, Gray's Inn-lane.—The stoppages are almost constant.

"Parker-street, Drury-lane.—Pipes failed and the brick sewer, to replace them, cost about £250.

"George-street, Hammersmith.—Pipes failed and the brick sewer, to replace them, cost about £15.

"Carrier-street.—The catch-pit, to the pipes in Harvey's-yard, costs about £80 per annum, to prevent the pipes from being choked up.

"Sydenham Common.—Pipes 18 inches in diameter are taken up, and a brick sewer is substituted for them.

"East-lane, Greenwich.—Pipes 18 inches in diameter are taken up, and a brick sewer is substituted for them."

Many other places are enumerated, where failures, or stoppages of pipe sewers have occurred.

Mr. Rawlinson said, he should not attempt a reply to the strictures upon the system of pipe sewers, or to the attacks upon the proceedings of the General Board of Health, because in his own practice, as an Engineer, he used his powers of discrimination and his experience, for determining the plan of his proceedings and the materials to be employed, and, also, because he thought the meetings of the Institution should rather be devoted to the discussion of professional practice, than to controversial disquisitions on the proceedings of public Boards.

In many of the statements made, he fully concurred; and he was ready to admit, that an indiscriminate application of the pipe-sewer system, could not be maintained. If, in his own practice, he had to treat a locality, where there was a sufficient water-flow to fill the cloaca maxima, he would give corresponding dimensions to his sewers; but if a sewer of 2 feet diameter would relieve a district of its sewage, he would not increase the dimensions merely for the purpose of internal inspection; in fact, he was so strongly impressed with the unnecessary inhumanity of causing men to enter sewers, that he would use any means rather than permit such a system; he would rather see the streets ripped up every year. The accretions, in sewers, were generally caused by the detritus from the roads and pavements; therefore it was important to devise a means of arresting it from going into the sewers. He conceived the question would be most convincingly settled by facts; and it was shown, that at Manchester there were many miles of pipe sewers, which had been in use for six, or seven years, without stoppage; at Liverpool there was also a great length of tributary pipe sewers; and in the Metropolitan districts there had been laid nearly two hundred miles of tributary pipe-drains. At Manchester the form was oval and the thickness considerable; but at Liverpool and in London, they were the ordinary tubular pipes, of the regular thickness.[1] With these, and numerous other corroborative facts before him, he could not forego his expressed opinion, of the applicability of pipe sewers, under certain circumstances and in localities adapted for them.

[1] Vide also, "Report to the Metropolitan Commissioners of Sewers, on the Drainage of Manchester and Leeds," by J. W. Bazalgette, 4th February, 1853.—Editor.

He contended, that floodings were not the result of pipe sewers alone; for instance, on the south side of the Thames, there were very large sewers at low levels; but no district was more inconvenienced by floods. There were many towns in the kingdom so situated, with regard to their outfall, that if the sewers were to be adapted to accommodate the storm water, as well as the house-sewage, they would not be drained at all.

He denied, that there were no means of discovering the position of stoppages in pipe sewers; by a careful examination of the state of the house-drains on each side of the sewer, the approximate locality of the stoppage was soon discovered, the ground could be opened, a pipe be removed, and another be laid down. It was true, that the obstruction might be more rapidly arrived at, from the nearest man-hole, and the accretion be removed from within, if the sewer was large enough, but there was, in his opinion, an insuperable objection to sending men down into sewers.

He had laid, and still continued to lay down, considerable lengths of sewer and drain pipes, as far as he knew, without the occurrence of any serious failures, or fractures; and, if due precautions were observed, such might always be the result. He had also constructed several miles of brick sewers, varying from 4 feet 6 inches by 3 feet, down to 18 inches in diameter; and he found, that if hollow bricks were used, the perforations being longitudinal, and the bricks laid as stretchers, not only was a good sewer constructed, but an efficient land drain was also provided.

In no instance had he attempted to separate the surface water from the foul house-water sewage; and the gullies, both from streets and yards, communicated direct with the sewers and drains.

As far as was practicable, pipe-sewers, of equal diameter, were never connected; but those of lesser section were joined into those of larger area; such as those of 6 inches into those of 9 inches diameter,—those of 4 inches into those of 6 inches diameter, &c. All secondary and house drains were joined to sewers, at as high a point as was practicable, an increased fall being given to them at the junction. Great attention to these points was required, as it was found, that a sewer, doing much work, was liable to become choked, if all the branches joined

on the same bottom level, and had not a corresponding volume of fluid passing through them.

Fig. 1.

Manhole, with junctions in Pipe Sewer. Section on the line A A, of Plan Fig. 2.

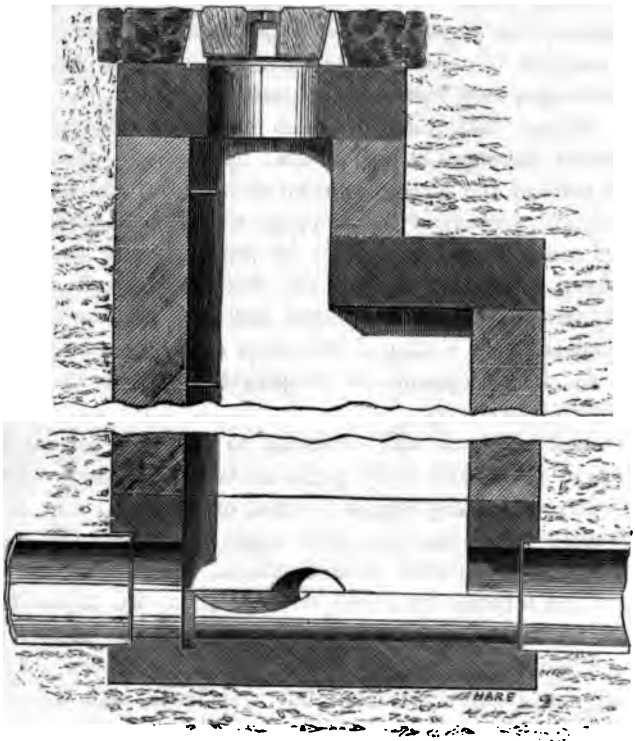


Fig. 2.

Plan of Bottom.

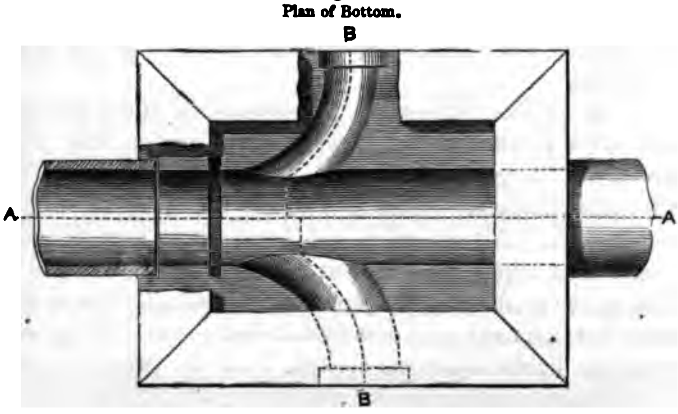


Fig. 3.
Lamphole on Pipe Sewer. Vertical Section.

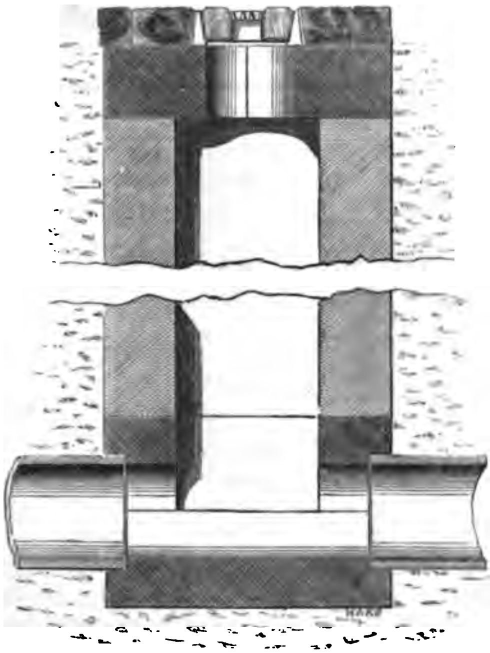
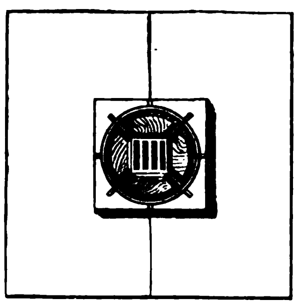


Fig. 4.
Plan of top of Lamphole, showing the cover.

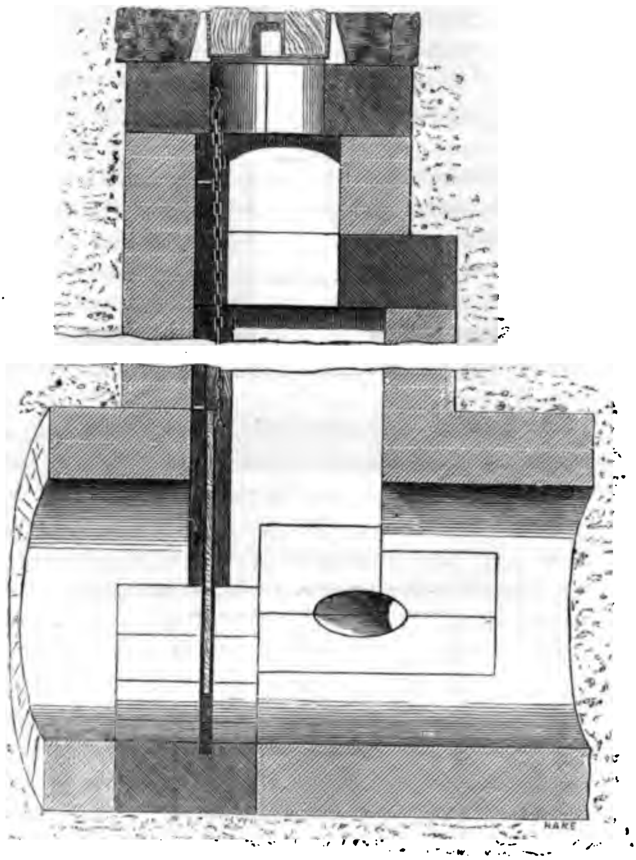


Manholes and lampholes, at short intervals, were requisite on lines of pipe sewers, and each intermediate length should be quite straight, in order that they might be examined and cleansed, if and whenever it became needful. At each manhole there should be an arrangement for flushing; and, in some

instances, a depth of 7 inches of deposit had been flushed out of a pipe of 15 inches diameter, in ten minutes, leaving the pipe-drain perfectly clean.

Fig. 5.

Manhole and Flushing Chamber, with junctions on Brick Sewer.
Section on the line A A, of Plan Fig. 6.

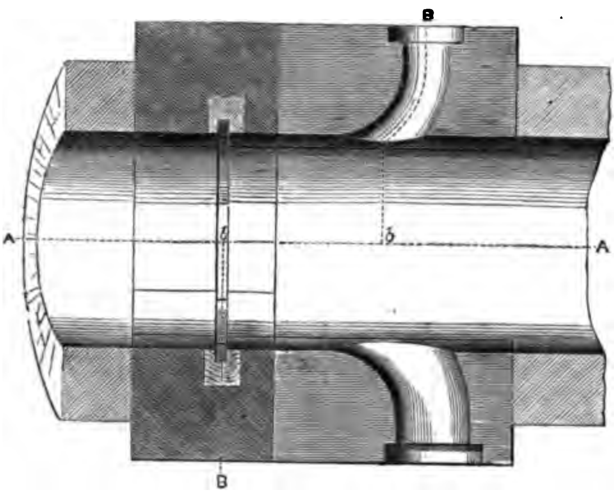


Precautions were necessary, to prevent sand, mud, or rubbish being introduced into the pipes whilst they were being laid; and the surfaces of roads, streets, and yards should be kept well cleansed, in order to prevent the dirt from being washed by heavy storms into and being deposited in the pipe sewers.

Woodcuts, Figs. 5, 6, 7, and 8, exhibited the details of a

manhole in a brick sewer, with side junctions from pipe-drains; and with a loose flushing-board fitting into a groove sunk in masonry. The manhole-cover could be lifted off by means of a key, in order that the sewers might be examined. Step-irons were fixed in all the manholes. All side junctions of pipe-sewers, or drains, with brick sewers, were made with stone. Junctions were also now made of earthenware, and were preferable. The lamphole-cover was removable, so that a lamp, or light, might be lowered opposite the end of the sewer, in order to discover any stoppage.

Fig. 6.
Plan of Invert.



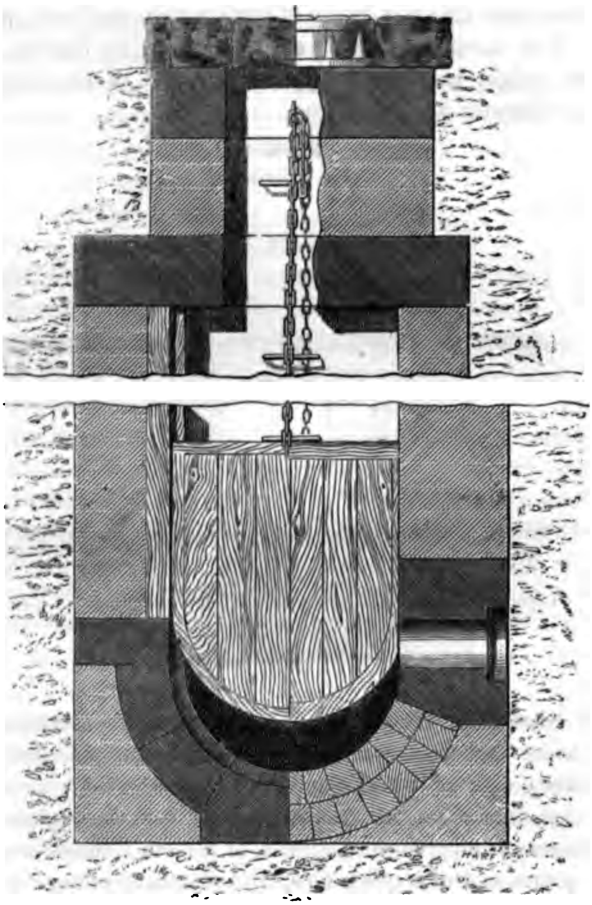
Mr. Rawlinson thought, that considering the lengths laid down, there had been very few failures in the pipe-drains, of the Surrey side of the Thames. He must still express his conviction, that pipes, for the purposes of drainage, offered the advantages of impervious substance, of smooth internal surfaces, of few joints, and of a quick flow, with cleansing power; instead of the permeable material, the rough surfaces, and the numerous joints of brick sewers, with the inherent sluggish motion and the natural tendency to accumulation.

He was not wedded to any system; but in practice he used such means as appeared best adapted to meet each case, and though, like other Engineers, he had not been exempt from

failures, he must give as the result of his experience, that they had occurred quite as often, in using the ordinary system, as with that which he had been accused of unduly advocating.

Fig. 7.

Section on the line B b B of Plan, Fig. 6.

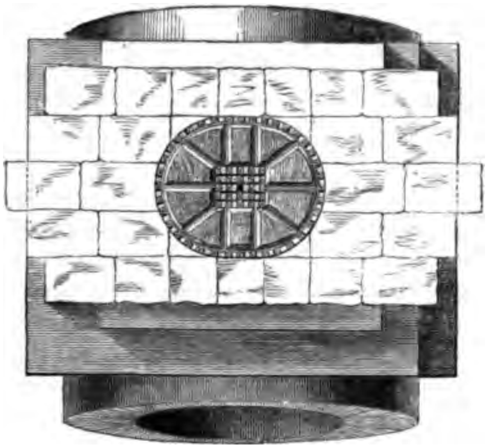


Mr. RENDEL,—President,—said although the Paper only professed to deal with the generalities of the question of the drainage of towns, it had been necessary to consider the materials employed in the execution of the works, as to Engineers the practice was as essential as the theory, and in fact it

appeared, that the failures had chiefly occurred from want of the former; although it was contended, that the latter was not by any means faultless.

Fig. 8.

Plan of top of Manhole, showing the Cover.



It had not been practicable to avoid direct allusions to the General Board of Health, and frequently in rather strong terms; but they were addressed to the official body and not to individuals, and then only for the published opinions, and the acknowledged practice of the officials, which were fairly open to animadversion; whereas, the strictures of the Board of Health, on the received practice of the profession, were as uncalled for and erroneous, as the theories promulgated in the blue-books published 'by authority.'

The object of the discussion had been, not to determine whether large sewers were superior, or inferior to pipe-drains, but to consider the broad question, of the most efficient system of drainage for towns, to ascertain the value of the general maxims that had been laid down, and the influence they might have on the sanitary condition of the country. In doing this, any allusion to public Boards had only been made, by quoting from their published documents, and to the extent only of the opinions they had given, in their public capacity.

It had been assumed, that several of the speakers had come to the consideration of the question, not only with preconceived

notions, but with a determination to condemn the pipe-drain system; this was so contrary to the spirit usually manifested at the meetings of the Institution, that he could not admit such a position, and the general tenor of the discussion proved, that the Engineers felt they could not receive as correct, either the statements put forth 'on authority,' or the deductions from the experiments; they had gone into the question of drainage, equally untrammelled by previous opinions, or by official dictation, and only animated by a desire to discuss the question on scientific and practical grounds, and for the ultimate benefit of the public.

The choice of the various qualities of the materials for pipes and bricks, for sewers, must be left to the judgment and experience of the Engineers; it was of considerable importance to the durability of the work; but so much depended on locality, that considering it would be better, not to import that branch of the subject into the chief question, which was the consideration of the system of town drainage to be recommended, and that the details of construction could be considered on another occasion, he had rather discouraged the discussion of the relative qualities of materials, and would suggest it as a good subject for a Paper during the next session.

The general question of sanitary reform was almost based on the adequate drainage of towns, and, it appeared to be admitted, by all who had directed attention to the subject, that the works, for the purpose, should be comprehensive and permanent, even at almost any reasonable cost, and with the example of Croydon before them, the authorities of even moderate-sized towns should hesitate, before, for the sake of economy, they submitted the drainage of the habitations of their fellow townsmen, to the risk of dependence on a system of inaccessible drains, instead of constructing adequately-sized main sewers. The investigations into the causes of the epidemic at Croydon, as well as the Reports ordered by the Metropolitan Sewers' Commissioners, relative to the results of the pipe-drain system in other localities, would materially aid, in arriving at the correct solution of this vital question, if undertaken with a right spirit, and from the character of the professional men who were engaged in them, there was little doubt of the valuable and impartial evidence which would be obtained.

The President trusted, that the subject would be soon again brought practically before the Institution, by an account of the complete sewerage of some large town, where both the systems of brick sewers and of tubular drain-pipes had been impartially tried.

November 30, 1852.

JAMES MEADOWS RENDEL, President, in the Chair.

THE discussion upon the Paper, No. 880, "On the Drainage of Towns," by Mr. Rawlinson, was renewed, and extended to such a length as to exclude all other business.

December 7, 1852.

JAMES MEADOWS RENDEL, President, in the Chair.

THE following Candidates were balloted for and duly elected: James Brunlees, Modèste Gallez, and John Willet, as Members; and John Boyd, Charles John Brydges, Pierre Hippolyte Boutigny (d'Evreux), Richard Rous Ellicombe, William Hawes, Alfred Charles Hobbs, William Jackson, M.P., Jabez James, Joseph Jopling, Jun., William McCormick, John Warner, and William Watson, as Associates.

The discussion upon the Paper, No. 880, "On the Drainage of Towns," by Mr. Rawlinson, was renewed, and continued throughout the evening, to the exclusion of any other business.

December 14, 1852.

JAMES MEADOWS RENDEL, President, in the Chair.

THE renewed discussion upon the Paper, No. 880, "On the Drainage of Towns," by Mr. Rawlinson, was continued throughout the evening, to the exclusion of any other subject.

ANNUAL GENERAL MEETING.

December 21, 1852.

JAMES MEADOWS RENDEL, President,
in the Chair.

MESSRS. R. Hopkins, J. Barrett, and J. Hill, were requested to act as Scrutineers of the Ballot, for the election of the President, Vice-Presidents, and other Members and Associates of Council.

The list of the attendances of the Members of Council for the past year was read, and the Ballot was commenced; the balloting papers being sent for examination, at intervals of fifteen minutes, in order to expedite the labours of the Scrutineers.

The Annual Report of the Council, on the proceedings of the Institution during the past year was read.

Resolved,—That the Report of the Council be received and approved; and that it be referred to the Council, to be printed and circulated with the Minutes of Proceedings, in the usual manner.

The Telford Medals and Premiums, and the Council Premiums which had been awarded, were presented.

Resolved,—That the thanks of the Meeting are due, and are presented to Messrs. Swann and Pole, for the readiness with which they undertook the office of Auditors of Accounts, and for the clear balance-sheet they have laid before the Meeting; and that Messrs. Pole and G. F. White be requested to undertake the office of Auditors of Accounts for the ensuing year.

Mr. Swann returned thanks.

Resolved,—That the thanks of the Institution be offered to Mr. J. Andrews for the truthful Portrait of the Past President, Sir John Rennie, painted by him, and presented to the Members,—and also to Mr. E. H. Baily, R.A., for the excellent Bust of Mr. Robert Stephenson, M.P., Vice-President, modelled by him and added to the collection of the Institution.

Resolved,—That the thanks of the Iustitution are justly due, and are presented to the Vice-Presidents, and other Members of the Council, for their co-operation with the President, their constant attendance at the Meetings, and their zeal on behalf of the Institution.

Mr. Simpson, V. P., returned thanks.

Resolved unanimously,—That the cordial thanks of the Meeting be given to Mr. James Meadows Rendel, President, for his strenuous efforts in the interest of the Institution, for his great attention to the duties of his office, and for the urbanity he has at all times displayed in the Chair.

Mr. James M. Rendel, President, having left the Chair, returned thanks.

Resolved unanimously,—That the cordial thanks of the Meeting be given to Mr. Charles Manby, the Secretary, for his constant zeal and attention to the interests of the Institution, the ability displayed by him in the execution of his duties, and his attention to the individual wishes of the Members.

The Secretary returned thanks.

The Ballot having been open more than an hour, the Scrutineers, after examining the papers, announced that the following gentlemen were duly elected to fill the several offices in the Council for the ensuing year:—

President,

JAMES MEADOWS RENDEL.

Vice-Presidents,

Isambard K. Brunel,	James Simpson,
Joseph Locke, M.P.,	Robert Stephenson, M.P.

Other Members of Council.

Members,

George P. Bidder,	John Hawkshaw,
Joseph Cubitt,	John R. McClean,
John E. Errington,	Charles May,
John Fowler,	John Penn,
Charles H. Gregory,	John Scott Russell.

Associates,

Thomas Brassey,	Thomas Russell Crampton.

Resolved,—That the thanks of the Meeting be given to Messrs. R. Hopkins, J. Barrett, and J. Hill, the Scrutineers, for the promptitude and efficiency with which they have performed the duties of their office, and that the ballot papers be destroyed.

ANNUAL REPORT.

Session 1852—53.

The period has again arrived, for the resignation of the trust confided to the Council, and for the election of their successors; and although the past year has not been attended with the same amount of public excitement as its predecessor, it has been a season of considerable interest to the profession generally, from the extraordinary development of public works. This has probably arisen, from a combination of circumstances; but it must, in a great degree, be ascribed to the discovery of those auriferous deposits of the other hemisphere, which have been beneficently designed, to bring into active utility, the humbler, but more permanently useful minerals of the parent country, and for supplying the wants of its rising colony.

Not only is the manufacturing class benefited, but the community, generally, appears aroused to action, and great public, as well as private projects, have been brought forward.

There has been a general demand for the improvement of towns, and more attention to the amelioration of the sewerage, watering, lighting, and paving; the main lines of railways are in progress of completion, and innumerable connecting branches are projected; the Electric telegraph is extending its wires, not only along the railways, but by the common roads, and beneath the channel, bringing our metropolis within speaking distance of the chief capitals of Europe; nor will it stop there, as by order of the Hon. East India Company, the presidencies of India will speedily be united, by electric wires, and we may fairly anticipate being soon in almost instant communication

with our Indian possessions. Nor will this be the only reduction of time, as by the augmentation of the size of steam-vessels, their improved lines of draught, the system of building and launching them complete, and almost ready for their first voyage, it may be anticipated, that great reduction in the time of the voyages will be effected, whilst further demands will be made on engineering skill, in the construction of docks expressly adapted to receive this large class of steam-vessels.

Not satisfied with this state of activity at home, we find our members engaged, in the exercise of their various professional duties, throughout the Continent, in Egypt, in India, in Russia, in Norway, Sweden, and Denmark, and everywhere, it is hoped, preserving, and extending that high character, which has ever been awarded to our profession.

Our transatlantic brethren are fast accomplishing the railway across the Isthmus of Panama, and the project for a ship canal in the same region, has been revived, by the survey, recently made for members of this Society.

Before terminating this rapid and imperfect allusion to some of the leading topics of the period, it is necessary to mention, the re-establishment, by private individuals, of that wonderful building, (the Crystal Palace,) in which specimens of the world's wealth were first exhibited to us, in a concentrated form, and as it would appear to be chiefly intended for combining recreation with the general instruction, and artistic education of the productive classes of society, so to wish it all success, in its praiseworthy objects.

It is hoped, that the works, naturally resulting from this professional activity, will be recorded, and presented at the meetings of the Institution; and it is the duty of the Council, to remind the older Members, as well as those recently elected, that they have hitherto much neglected the engagements entered into, on joining the Society, and that unless good papers are prepared by the Members, the interest of the meetings will be diminished, and the utility of the Institution must decrease.

The principal papers, read during the past session, were "An Investigation of the Strains upon the Diagonals of Lattice-Beams," by W. T. Doyne and W. B. Blood; "Description of a new [illegible]meter," by Eugène Bourdon (Paris); "On

the Application of Machinery to the Manufacture of Rotating Chambered-breech Fire-arms," by Colonel Sam Colt (U. S. America); "Account of the Works on the Birmingham Extension of the Birmingham and Oxford Junction Railway," by C. B. Lane; "On the Alluvial Formations, and the Local Changes, of the South-Eastern Coast of England, from the Thames to Portland," by J. B. Redman; "Description of a Cast-iron Viaduct, at Manchester," by A. S. Jee; "Description of a Cast-iron Viaduct, at Salford," by J. Hawkshaw; "The Construction and Duration of the Permanent Way of Railways in Europe, and the Modifications most suitable to Egypt, India, &c.," by W. B. Adams; "On the Electric Telegraph, and the principal improvements in its construction," by F. R. Window; "The History, Theory and Practice, of the Electric Telegraph," by C. C. Adley; "On Tubular Marine Boilers," by Admiral the Earl of Dundonald; "On the Construction of Marine Boilers," by J. Scott Russell; "Description of a Diaphragm Steam-generator," by P. H. Boutigny (d'Evreux, France); "Account of the Drainage of the Town of Richmond, Surrey," by G. Donaldson; "Account of a Swing-Bridge, over the River Rother, at Rye," by C. May; "Description of the Lattice-Beam Viaduct across the River Nore, Kilkenny," by Captain W. S. Moorsom; "The Economy of Railways," by B. Poole; "Railway Accidents," by Captain M. Huish; and "Observations on Artificial Hydraulic, or Portland Cement," by G. F. White.

To a number of these papers, Telford Medals and Council Premiums of Books have been awarded:—

A Telford Medal, in Silver, to Captain Mark Huish, Assoc. Inst. C. E., for his paper "On Railway Accidents."

A Telford Medal, in Silver, to Braithwaite Poole, Assoc. Inst. C. E., for his paper "On the Economy of Railways."

A Telford Medal, in Silver, to Colonel Sam Colt (U. S. America), Assoc. Inst. C.E., for his paper "On the Application of Machinery to the Manufacture of Rotating Chambered-breech Fire-arms, and the peculiarities of those Arms."

A Telford Medal, in Silver, to Frederick Richard Window, Assoc. Inst. C. E., for his paper "On the Electric Telegraph, and the principal improvements in its construction."

A Telford Medal, in Silver, to Charles Coles Adley, for his

paper, entituled "The History, Theory and Practice of the Electric Telegraph."

A Telford Medal, in Silver, to Eugène Bourdon (Paris), for his "Description of a new Metallic Manometer, and other Instruments for measuring Pressures and Temperatures."

A Telford Medal, in Silver, to Pierre Hippolyte Boutigny (d'Evreux), for his "Description of a new Diaphragm Steam Generator."

A Telford Medal, in Silver, to George Frederick White, Assoc. Inst. C. E., for his "Observations on Artificial, or Portland Cement."

A Council Premium of Books, suitably bound and inscribed, to John Baldry Redman, M. Inst. C. E., for his paper "On the Alluvial Formations, and the Local Changes, of the South-Eastern Coast of England, from the Thames to Portland."

A Council Premium of Books, suitably bound and inscribed, to William Thomas Doyne, Assoc. Inst. C. E., and to Professor William Bindon Blood, for their paper, entituled "An Investigation of the Strains upon the Diagonals of Lattice-Beams, with the resulting Formulæ."

A Council Premium of Books, suitably bound and inscribed, to George Donaldson, Assoc. Inst. C. E., for his paper "On the Drainage and Sewerage of the Town of Richmond (Surrey)."

A Council Premium of Books, suitably bound and inscribed, to Professor Christopher Bagot Lane, Assoc. Inst. C. E., for his "Account of the Works on the Birmingham Extension of the Birmingham and Oxford Junction Railway."

A Council Premium of Books, suitably bound and inscribed, to William Bridges Adams, for his paper "On the Construction and Duration of the Permanent Way of Railways in Europe, and the modifications most suitable to Egypt, India, &c."

All these papers possess so much merit, that an attempt to distinguish any one would be invidious, and their importance was shown by the useful discussions which they induced.

The treatises, by Captain Huish and Mr. Braithwaite Poole,

on questions of railway management, interesting as they were, have only opened the subject, and it is hoped, that an annual record of this important branch of social economy, will be laid before the members, during every session.

Colonel Colt's description of the application of machinery, to the manufacture of his Repeating Chambered-breech Fire-arms, fully merited the attention it received, from its demonstrating the advantages of self-acting machines, for saving manual labour, insuring uniformity between the several parts and perfect accuracy in the finished production; it was also the first American communication, ever laid before the Institution, and its favourable reception, at the meeting, tended in a great degree to determine the Author, in the formation of an establishment, for the manufacture of the arms in London.

The papers by Mr. Window and Mr. Adley, are, perhaps, the most comprehensive treatises hitherto produced, on the History, Theory, and Practice of the Electric Telegraph, and the principal improvements in its construction; this discovery has already worked, and must still produce, extraordinary results, not only in facilitating the transmission of important political and private communications between distant places, regardless of intervening obstacles, but, also, enabling mercantile and monetary transactions to be carried on without loss of time, whilst to it, also, must be, in a great degree, attributed the safety of the system of railway travelling, which under certain circumstances, would be partially arrested, but for the aid of this simple and beautiful contrivance.

To M. Eugène Bourdon, (of Paris,) the Institution is indebted, for the introduction of a simple and efficient instrument, for measuring pressures, and temperatures, which is calculated to be extensively useful to engineers; and to M. Boutigny (d'Evreux) for the description of a Steam Generator, resulting from his well-known investigations, on the spheroidal form, assumed by fluids, exposed to high temperatures. It is hoped, that many more communications will be received, from foreign engineers, and that a regular interchange of theoretical, and practical knowledge, may be established.

Mr. White's description of the Properties of Portland and other Artificial Cements, alluded to the use of that material, at

the jetty of the Harbour of Refuge, at Dover, of which works, it is hoped an account will be given, at an early period; the necessity for that, and other similar structures, having been so well demonstrated in Mr. J. B. Redman's paper on the Local Changes of the South-Eastern Coast of England, which afforded a good field for an animated discussion, and which subject will, it is hoped, be continued by the Author, from Portland to the mouth of the Severn, with the same careful observation as distinguished the first paper. It should be noticed, that this is the third premium obtained by Mr. Redman, and it is hoped, that his good example may be followed.

The investigation of the Strains upon the Diagonals of Lattice-Beams, by Mr. Doyne and Professor Blood, was not only highly creditable to the theoretical knowledge, and practical skill of the Authors; but had the merit of producing a very interesting discussion, and of inducing the promise of another paper on an analogous subject for a future Session.

Mr. Donaldson's paper, on the Drainage of Richmond (Surrey), opened a large field for observation, from whence, it is anticipated, much good must result; as by the practical truths, uttered by experienced engineers, in the discussions at the Institution, the public mind must be influenced; and with the knowledge of this fact before them, the Members will, doubtless, address themselves to the consideration of the subject, with a due disregard for preconceived notions, or authoritative dicta.

The description of the Railway Works, at Birmingham, by Professor Lane, contained much useful practical information; and the opinions of Mr. Adams, on the Construction of the Permanent-way of Railways, were calculated to induce deeper investigation, into a very important branch of engineering science.

To Mr. Jee, and to Mr. Hawkshaw, the Institution is indebted, for descriptions of Cast-Iron Viaducts; to Mr. May for an account of an Iron Swing Bridge, and to Captain Moorsom for a notice of a Timber Lattice Bridge, which introduced a good discussion; whilst Admiral the Earl of Dundonald, and Mr. Scott Russell contributed to the usefulness of the meetings, by their interesting communications on Steam Boilers.

The Volume of Minutes of Proceedings, for the past Session, forming Volume XI., is partially printed, and will be issued, with such completing portions of the former volumes, as the finances of the Society will permit.

From the Lords Commissioners of the Admiralty, through Admiral Sir F. Beaufort, and from the Honourable Board of Ordnance, the Institution continues to receive valuable contributions to its collection of charts, maps, &c.; and though, by the lamented decease of Major-General Colby, a zealous coadjutor has been lost, it is hoped that his successor may entertain, towards the Society, the same liberal views as those which animated your late Honorary Member.

Among the presents will be found, donations of several series of valuable books, and those from Mr. H. A. Hunt, and Mr. W. Radford, deserve special notice. The former contributed a complete set of the Encyclopædia Metropolitana, in twenty volumes, with Appendices, and the latter, the collected works of Sir Humphry Davy, in nine volumes, in conscientious fulfilment of the engagement, to write a paper, or to present some work for the library, within twelve months, from the period of their election. These and many other presents were selected by your Secretary, to whom the donors expressed their intentions and transmitted the funds required for the purpose.

Two other presents should be particularly mentioned; the first is the portrait of your past President, Sir John Rennie, painted by Mr. James Andrews, and offered, by that gentleman, to the Institution. The picture is now before you and it is confidently hoped, it may receive your commendation, for its artistic merit and truthful portraiture, as well as your cordial concurrence in the vote of thanks, which the Council would propose to offer to the Artist, who has promised to produce an engraving of the picture, to correspond with those of your previous Presidents.

This picture affords an opportunity for again suggesting a continuation of the series of portraits of the past Presidents, commenced by the first, and now extended to that of the third occupant of the presidential chair; as also for reminding the Members, that this Institution is the fitting depository for portraits of the Members of the profession, whose race is

run, but the remembrance of whose deeds should be ever before us.

The other is the bust of Mr. Robert Stephenson, M.P., V.P., and for its excellence, as a work of art, and the kind feeling which prompted the presentation of the likeness of one of your body, who is equally esteemed by all, in his public as in his private capacity, the Council feel assured you will cordially agree in the talented sculptor, Mr. E. H. Baily, R.A., being entitled to your best thanks.

The Balance Sheet drawn up by the Auditors, (pages 124 and 125) exhibits an abstract of the receipts and expenditure of the funds of the Society during the past year.

The amount of arrears of subscriptions for 1852, due November 30th, is,—

	£. s. d.	£. s. d.
From Members of all classes, residing abroad	70 17 6	
From Members of all classes, residing in England	220 19 0	
		291 16 6
Total amount of arrears of the previous years, exclusive of 1852 is,—		
From Members of all classes, residing abroad	407 17 6	
From Members of all classes, residing in England	553 4 0	
		961 1 6
Total		£1,252 18 0

The collection of the current subscriptions has been extremely good; but the amount of arrears of previous years having increased, it has become necessary to take some positive step; the Council have, therefore, been compelled to give notice to the Members of all classes, whose subscriptions are more than two years in arrear, that unless a satisfactory arrangement be made, before a given period, the provisions of Clause 10, Section V. of the Bye-laws, will be enforced, and their names will be erased from the Register of the Institution.

The tabular statement of the transfers, elections, deceases, and resignations of Members of all classes, during the years 1850-51, and 1851-52, appears thus:—

—	Honorary Members.	Members.	Associates.	Graduates.	Annual Increase.
1850-51.					
Transferred to Members . . .	..	..	2	1	
Elections	1	3	52	..	56 − 23 = 33
Deceases	1	5	6	..	} = 23
Resignations	..	1	9	1	
1851-52.					
Transferred to Members . . .	..	..	4	..	
Elections	..	8	42	..	50 − 21 = 29
Deceases	3	8	3	1	} = 21
Resignations	..	..	3	3	
Members of all classes on the books	30	251	438	26	= 745

If the Honorary Members and Graduates are omitted from the calculation, the annual increase of Members and Associates stands thus:—

Years.	Members.	Associates.	Members elected.	Deceases, Resignations, and Erasures.	Effective Increase.
1847	8	21	29	19	10
1848	11	27	38	22	16
1849	18	31	49	11	38
1850	7	31	38	27	11
1851	3	52	55	21	34
1852	8	42	50	14	36

The following Members, Associates, and Graduates, having tendered their resignations, after arranging the several amounts of subscription due, have been permitted to retire from the Institution, in accordance with Clause 9, Section V. of the Bye-laws:—

Sören Hjorth, Joseph Tregelles Price, and William Radford, Associates; Siegerich Christopher Kreeft, John William Power, and John Smythe Robinson, Graduates.

Among the deceases, which are very numerous, will be found the names of several well-known Members of the profession,

and those of three Honorary Members, one of whom occupied a high position in the scientific world, another who was at the head of the Trigonometrical Survey of the Kingdom, and the third a distinguished warrior and statesman, whose unusually prolonged life has been entirely spent in the service of his country.

The deceases are, F. M. the Duke of Wellington, Major-General Thomas Colby, and John George Children,—Honorary Members;—John Barnes, David Bremner, Robert Brunton, Tommaso Cini, William Tierney Clark, Frank Forster, Thomas Grainger, and Walter Hunter,—Members;—Sir Josiah John Guest, Bart., M.P., John Sylvester, and Henry Vint,—Associates;—and Henry Charles Rawnsley,—Graduate.

The Council regret, that of some of these gentlemen, it has only been possible to prepare imperfect memoirs, on account of the unwillingness to supply to the Secretary that information, without which it is impracticable for him to draw up notices of the career of the deceased Members.

The memoirs will be found in the Appendix to this Report;—page 126.

In the balloting list for the President, Vice-Presidents, and Members of Council, the only change is the omission of the name of Mr. Joseph Miller, who expressing his deep sense of the kindly feeling manifested towards him, by his repeated election, whilst the state of his health was such as to preclude his attendance at the meetings, and seeing no immediate prospect of such a return of strength, as to encourage a hope, of being able to devote himself, as he would wish, to the duties of the post, has signified his desire to withdraw from the Council; requesting that his thanks may be communicated, for the kind consideration exhibited to an invalid, and the assurance, that he shall always entertain the same sincere wishes, for the collective and individual welfare of the Members, and the continued prosperity and advancement of the Institution.

The former Members of Council are proposed for re-election, and to the list, in conformity with the Bye-laws, the names of Mr. Peter William Barlow, Captain William Scarth Moorsom, and Mr. John Penn, are added.

The two Associate Members retire annually, and the names

of Messrs. Thomas Brassey, Thomas Russell Crampton, Henry Arthur Hunt, and William Piper, are submitted, from which to select their successors.

The Council now resign the trust confided to them, believing that the review of the proceedings of the past year, will have been gratifying to all, and yet be only the foreshadowing of a much higher state of prosperity and utility, which, however, can only be arrived at, by a determination, on the part of each individual Member, to use every effort for extending the sphere of usefulness of the Institution, and for placing it in a conspicuous position, among the scientific societies of the world.

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS.

Dr.	£.	s.	d.	£.	s.	d.
To Balance in the hands of the Treasurer				82	17	10
— Subscriptions and Fees:—						
Arrears	240	9	0			
Current	1,567	6	0			
Fees	151	4	0			
Life	54	13	0			
				2,013	12	0
— Council Premiums				47	10	0
— Publications:—Sale of Minutes of Proceedings				123	11	6
— Telford Fund:—Dividends, one year and a half				85	0	3
				£2,352	11	7

from the 1ST DEC., 1851, *to the* 30TH NOV., 1852.

PAYMENTS.

Cr.	£.	s.	d.	£.	s.	d.
By House, Great George Street, for Alterations				3	8	3
Ditto, for Rent	364	1	2			
Rates and Taxes . . .	40	1	2			
Insurance	18	19	9			
				423	2	1
— Salaries				300	0	0
— Commission on Collection of Subscriptions				122	3	7
— Clerk, Messenger, and Housekeeper				226	10	6
— Postage and Parcels:—						
General	78	0	6			
Parcels	1	0	6			
				79	1	0
— Stationery, Engraving, and Printing Circulars, Cards, &c. .				37	12	8
— Coals, Candles, Oil, and Gas:—						
Coals	19	3	0			
Candles	5	8	3			
Gas	45	3	0			
				69	14	3
— Tea and Coffee				40	14	5
— Library:—						
Books	11	0	6			
Periodicals	15	10	3			
				26	10	9
— Publication:—Minutes of Proceedings				669	4	0
— Telford Premiums				3	9	8
— Council Premiums				11	9	1
— Diplomas for Members				9	9	8
— Manuscripts, Original Papers, and Drawings				4	17	5
— Incidental Expenses:—						
Sending Invitations and Cards, procuring Models, &c. for Conversazione . .	93	6	9			
Gratuities and Christmas Gifts . . .	1	9	6			
Occasional Assistance	3	6	6			
Assistance at Meetings	8	12	0			
Beating Carpets and Sweeping Chimneys, &c.	8	5	0			
Household Utensils, Repairs, and Expenses	50	9	5			
				165	9	2
				2,192	16	6
— Balance in the hands of the Treasurer				159	15	1
				£2,352	11	7

Examined and compared the above Account with the vouchers entered in the Cash Book, and find them to be correct, leaving a balance in the hands of the Treasurer of One Hundred and Fifty-nine Pounds Fifteen Shillings and One Penny.—November 30th, 1852.

(Signed) WILLIAM SWANN, (Acting for J. G. APPOLD,) WILLIAM POLE, } *Auditors.*

CHARLES MANBY, *Secretary.*

December 20, 1852.

APPENDIX

TO THE

ANNUAL REPORT.

MEMOIRS.

ARTHUR WELLESLEY, DUKE OF WELLINGTON, Prince of Waterloo, Captain-General of Spain and Portugal, and Field-Marshal of Great Britain, and of seven other countries, was born (according to the most accredited authorities) on the 29th of April 1769, in Upper Merrion Street, Dublin, and after an unusually prolonged career of unceasing activity, as a warrior and a statesman, he terminated a life entirely devoted to the service of his country, on the 14th of September 1852, in the proud consciousness, that in his firm determination to perform his duty, under all circumstances, he enjoyed the sympathy and commanded the respect of his countrymen, beyond any other man of his day.

Such might, with propriety, be the brief notice of our late illustrious Honorary Member, and after all that has been so industriously collected and so well related, by eminent writers, it would be a work of supererogation to do more, than notice, very succinctly, a few points in the Duke's civil life, by which he was brought more immediately into contact with the Members of this Institution.

It is a question whether the apparent deficiency of early promise, exhibited by Arthur Wellesley, at Eton and at the military seminary of Angers, may not be attributed to the absence of necessity for action, rather than to want of capacity;

for at a very early period in his military career, we find him giving evidence of a clear comprehension of a difficult position, and great decision in executing his resolves. In India, he had ample opportunities for developing, correcting, and maturing, those talents for organization and systematizing, which were, subsequently, so eminently exhibited, during the Peninsular War; not only in directing strategic movements in face of superior numbers, but in organizing the Commissariat for the material wants of an inadequate force, irregularly and scantily supplied with necessaries, which it was peremptorily requisite to provide; for, (using the words of an eminent French writer,[1] whose short sketch is, at the same time, the truest and most graphic, that has appeared,) the Duke knew that "the English soldier does not like to feed upon imagination, and with an empty stomach, he does not much care for being contemplated by forty centuries."

The feeling of confidence, induced on the minds of the troops, by his known foresight, may have been part of the secret of his great success; for if he was not generally beloved he was universally respected and trusted, and if he did not exercise the dazzling powers of fascination, possessed by Cæsar, and by Napoleon, the soldiers knew, that he was always mindful of their professional wants, always jealous of their honour, and, above all, invariably conducted them to victory.

It has been said, that "during his whole life Wellington was a man of resistance,"—this may be true, but his resistance was the result of conviction; as he had been in war, so he became in politics; he was not an advocate for reform, but when the proper time arrived he stepped forward and gave even more than was asked. Although a warrior, his great object was the establishment of peace, on a firm basis; and during his campaigns his earnest solicitude was to diminish the horrors of war. "Though the greatest warrior who has ever been amongst us, he had the greatest horror of the miseries of war; every effort and energy of his mind, in the field, in the camp, and in the

---

[1] "Wellington, from a French point of view," by John Lemoine; a sketch which appeared, originally, in the "Journal des Débats," and was re-written in English, by the Author, in accordance with an opinion expressed by some English friends, that a French critic's view of their great countryman's character might be acceptable to the English public.

senate, was directed, not merely for the attainment of glory, but because he always looked forward to that victory, for which he struggled, as a security to his country for the blessings of a lasting peace." He asserted, on all occasions, the pre-eminence of the Civil law; contending "that Martial law was merely the execution of the arbitrary will of the Commander, in fact, that Martial law meant no law at all,"—and that military power should be used to enforce the law of the land, only when the civil force was unequal to the assertion of its supremacy.

Animated by these sentiments, although he made the most complete military arrangements, for the effective suppression of the anticipated Chartist outbreak, on the 10th April 1848, and by retaining possession of the bridges over the Thames, he outmanœuvred the insurgents, not a bayonet was visible, and the preservation of the peace of the Metropolis was, apparently, intrusted entirely to the Civil power and to the keeping of its own citizens, and the Continent received another proof, if such was wanting, of our English love of order and our respect for the law of the land; demonstrating "to what an extent, reliance may be placed on a population, upon whom the strongest hold of the Government is, their own reverence and respect for the free institutions of their country, and the principles of popular self-government controlled and modified by a constitutional Monarchy."

He was essentially a practical man,—a man of application, —and to him might be applied his own dictum, that "If the world was to be governed by principles, nothing would be more easy, than to conduct even the greatest affairs; but in all circumstances, the duty of a wise man was to choose the lesser of any two difficulties which beset him."

It does not appear to have been generally perceived, that there was a wonderful resemblance between the two modern heroes of the Anglo-Saxon-race—Wellington and Washington; "They were both endowed with the same heroic simplicity of character, and aversion to theatrical display; the same sobriety of judgment,—sagacious apportionment of means to an end,—unshaken resolution and fortitude,—the same clear integrity,—the same devotion to the principle of duty,—the same infrangible perseverance,—the same labours, and both attained the same durable and triumphant success! Both these great gene-

rals had to create their armies; to struggle with inadequate forces against a superior foe, covered with renown, and fresh from the fields of victory!—to weld the same rude materials into a disciplined engine of war. Wellington in the lines of Torres Vedras, scorning alike the provocations of his enemies, and the impatience and clamours of his own army and nation—wherein did he differ from Washington in the camp of Valley Forge, surmounting the like tribulations with the like unconquerable resolve? The difference is in the scene, not in the men,—between the rugged sierra and the boundless savannah. Even in their cause they differed not so much, as the leader of a revolution, and the champion of ancient order, might be supposed necessarily to do. The aristocrat Wellington, and the republican Washington, alike undertook the defence of the sacred and inalienable rights of their fellow-men. If the one achieved the freedom of his country, the other secured that of his native land, with the same firm and tranquil conviction of the righteousness of their cause. Both were successful warriors, who yet loved not war,—who gladly sheathed the sword of their battles, and who reluctantly placed their hands on the hilt again—happily not to draw the weapon in any meaner conflict, still more happily, not in the civil strife, which at one time seemed to threaten both.

"Until the latter years of both these great men, the people had not learned thoroughly to appreciate their tranquil goodness and greatness, and then it was too late for enthusiasm and complete confidence between them. But the touch of death seemed to dissolve the spell that separated the popular feeling from the full appreciation alike of Washington and Wellington; and henceforth they are enshrined in the hearts, as well as the memories of their countrymen."[1]

The remarkable coincidences in the career of the Duke and of his great rival in the field, the Emperor Napoleon, were eloquently and feelingly alluded to by Mr. Gladstone (the Chancellor of the Exchequer), when he requested the attendance of the Members of the House of Commons at the interment of the Duke, "to recognise in the face of the country,

[1] Extract from a MS. Memoir of the Duke, by the talented Author of "Whitefriars," "Westminster Abbey," &c.

and of the civilised world, the loss of the most distinguished of our citizens, and to offer to the ashes of the great departed, the solemn anguish of a bereaved nation. The princely personage, who has left us, was born in an age more fertile of great events than any period of recorded time. Of those past incidents, the most conspicuous were his own duties. They were performed with the simplest means, and with the greatest honour. He was, therefore, not only a great man, but the greatest of men in a great age. Amid the chaos and conflagrations that attended the close of the last century, there arose one of those men who seem born to master mankind. It is not too much to say, that Napoleon combined the imperial ardour of Alexander with the strategy of Hannibal. Kings of the earth fell before his powerful genius, and he denounced destruction against the only land which dared to be free. The Providential superintendence of the world seemed scarcely ever more manifest, than when we recal the dispensation, that the same year should produce the French Emperor and the Duke of Wellington; that in the same year they should have embraced the same profession; and that, natives of distant islands, they should both have repaired for their military education to that illustrious land, the cradle of warriors. During that long struggle for our freedom, our glory, and, I might say, our existence, Wellesley fought and won fifteen pitched battles of the highest class. During this period, that can be said of him which can be said of no other general—that he captured three thousand cannon from the enemy and never lost a single one. But the greatness of his exploits was perhaps even surpassed by the difficulties which he had to encounter."——"The star of Wellesley never paled. He has been called fortunate, for fortune is a divinity that ever favours those who are at the same time sagacious and intrepid, inventive and patient. It was, however, his own character that achieved his exploits and guarded him from every vicissitude, for it was his sublime self-control that regulated his lofty fame."

One of the Duke's early acts, was his co-operation with his friend Sir Robert Peel, in the establishment of the constabulary force in Ireland. At Seringapatam, after serious evils had been experienced, from a long-standing debasement of the Indian coinage, he found time to address a memorial to the Presidency,

containing predictions and observations, all of which have been verified by subsequent events. So during the most critical juncture of the Peninsular War, he drew up a very able paper, on the true principles of Portuguese banking.

In his celebrated Despatches, passages constantly occur, giving in terse language, the soundest opinions, on the civil state of the country.

This administrative feeling probably induced his acceptance of the post, of Master of the Corporation of the Trinity House, to the duties of which he was most attentive;—to him Sir Isambard Brunel confidently appealed, for the assistance of Government, in the completion of the Thames Tunnel;—his countenance and support were unhesitatingly given for the construction of Waterloo and New London Bridges;—and by his constant attention, as Lord Warden of the Cinque Ports, to the improvements at Dover Harbour, he was continually brought into contact with one of our past Presidents, and other Members of this Institution.

He assisted in 1830, at the inauguration of the Liverpool and Manchester Railway, when the genius of Stephenson secured to this country another of the crowns of practical science; and the prescience of the Duke was not slow to perceive the new power placed in his hands, for the defence of this insular kingdom; particularly when by the electric telegraph, his commands could be transmitted with lightning speed. He lived also, to witness and rejoice in the triumph of the peaceful arts, in the erection of that wonderful crystal structure, which by its novelty, simplicity, and magnitude, created nearly as much interest as the remarkable industrial collection it so worthily enshrined. The interest he evinced in the progress of the period, was not a mere matter of form, but such as a mind, gathering light till its close, might be supposed to take in the successive victories of practical science.

He was elected an Honorary Member of this Society in the year 1842, frequently visited it, and was always ready to aid its objects.

Of the decease of the Duke it may be truly said, the column of granite, which divided the brewing elements of strife, is broken, and HE alone, who governs all things, can raise up the successor of the Iron Duke; his death is the fall of another

large stone "from the European fabric, and the present generation, anxiously bending over the gulf of the future, listens with awe for its fall into the unfathomable deep."

MAJOR-GENERAL THOMAS F. COLBY, was born at Rochester, on the 1st of September 1784: on his father's side he descended from the ancient and wealthy family of the Colbys of Rhos-y-Ghilwin, Pembrokeshire; and among his maternal ancestors, were numbered, General Hadden of the Royal Artillery, Surveyor-General of the Ordnance, Colonel Hadden, Paymaster-General of the Forces in Portugal, and Captain Hadden, who distinguished himself at the siege of Belleisle. His father was Major Colby, of the Royal Marines, who performed brilliant services on several occasions, but especially under Lord Howe, on his glorious victory of the 1st of June, 1794, when he was severely wounded.

Thomas Colby received the first part of his education from Dr. Crockell, at the Northfleet School, whence he was transferred to the Royal Military Academy, at Woolwich, and in December 1801, at the age of seventeen, he received his commission, as a Second Lieutenant in the corps of Royal Engineers, when Major Mudge, the Superintendent of the Trigonometrical Survey, fully appreciating the qualifications already displayed by the young Engineer, obtained permission from the Master-General of the Ordnance, to attach him, as his assistant, to the Survey in January 1802. Shortly after this, in 1803, when on a visit of inspection, to Mr. Robert Dawson, of the corps of Royal Military Surveyors and Draughtsmen, then conducting the topographical portion of the Ordnance Survey, in Cornwall, and since so distinguished for the topographical sketches of Wales, he met with a serious accident from the bursting of a pistol, by which his hand was so shattered as to render necessary its amputation at the wrist, and his forehead received a mark which was never obliterated.

A vigorous constitution, assisted by the kind care of his friends, carried him through this trial, and on his recovery, his services were immediately called into requisition, for the principal triangulation, and the measurement of the arc of the

meridian, between the Shetland Isles and the Isle of Wight. Numerous traditionary recollections are still cherished, by his few surviving friends, of the extraordinary personal energy, which enabled him, during that period, to triumph over climate and country in the wilds of Scotland, and to accomplish his delicate observations, with minuteness and accuracy, under circumstances which would have discouraged most men. A part of each year was also spent, at the Tower of London, in computing and preparing for publication, the results of the previous observations; as also in the construction and engraving of the Ordnance Maps.

His intimate association with the labours of Lieut.-Colonel Mudge may be judged of, from the third volume of the "Trigonometrical Survey of England," published in 1811, which contains "an account of the Trigonometrical Survey, extending over the years 1800 to 1809, by Lieut.-Colonel William Mudge of the Royal Artillery, F.R.S., and Captain Thomas Colby, of the Royal Engineers." It might be added, that in consequence of the declining health of General Mudge, he conducted the Sector Observations, in Shetland, whilst M. Biot, who was on this occasion associated with him, made his equally interesting observations with the pendulum. His scientific qualifications and practical skill, were so generally acknowledged, that on the decease of Major-General Mudge in 1820, he received from the Duke of Wellington, the appointment of Superintendent of the Trigonometrical Survey, upon the strong recommendation of Sir Joseph Banks, then President of the Royal Society.

Meanwhile he successfully attained the ranks of First Lieutenant in 1802,—Second Captain in 1807, Captain in 1812—and Major, (by brevet) in 1821; and at that period he was associated with the late Captain Kater, and MM. Arago and Mathieu, in the verification of the connexion between the Observatories of Greenwich and Paris.

In 1824, after a careful investigation of the question, by a Committee of the House of Commons, the Survey of Ireland was ordered to be made; and being directed by the Master-General of the Ordnance, to plan and superintend its execution, Major Colby entered upon the task with all the skill and energy he so pre-eminently possessed. This was really the great work of his life, for which all his previous labours were only the

fitting preparation, and for this he may be said, to have created the means of execution, whilst devising the mode of proceeding. On it he employed, not only the Royal Sappers and Miners, but also the Irish peasantry; bringing into harmonious action, the labours of about forty observers and of several hundred surveyors and draughtsmen. Not approving the differential rods used by the French philosophers, or the measuring bands of mica, proposed by the late Captain Drummond, he invented the compensation bars, which bear his name, and would alone suffice to give to their author a claim to a high place, in the list of improvers of geodetic science.

In connexion with the field labours, it was essential to establish an equally perfect office, for recording the observations and drawing and engraving the maps; and hence arose the Survey Office, at Mountjoy, in the Phœnix Park, Dublin; where, under the immediate superintendence of Captain (now Lieut.-Colonel) Larcom, R.E., that system of accuracy and beauty of work, was attained, which has stamped so high a reputation on the Irish Survey: and that establishment, superior in all its details to the old Map Office, in the Tower, served as a model for the Map Office, at Southampton, which is, in fact, only its reflected image.

Major Colby was not only fully aware of the direct advantages of an accurate survey of the surface of the country, but was the first to point out the collateral benefits, to be derived from combining with it searching investigations into the geology, mineralogy, natural history, statistics, and antiquities of the country, and his reports to Sir Henry Hardinge, then Clerk to the Ordnance, the collections of minerals and fossils, &c., made in connection with the Survey, the "Memoir of Londonderry," drawn up under his directions, by Captains Larcom and Portlock, and Messrs. Petrie and Donovan, and the able "Report of the Geology of Londonderry and Tyrone," by Captain (now Lieutenant-Colonel) Portlock, R.E., in 1843, without doubt suggested the Statistical Papers of the Irish Census Commission, drawn up by Major Larcom, and induced the establishment of the Geological Survey, which latter in the able hands of Sir Henry de la Beche and his assistants, Professors Phillips, Forbes, Ramsay, Lyon Playfair, Percy, Jukes, Hooker, &c., has been productive of so much benefit.

It would not be practicable, within the limits of this sketch, to even mention the principal facts connected with the Surveys, but it is imperative to allude to one operation, in which Major Colby felt great pride—the measurement, with his compensation-bars, and under his personal superintendence, of the great base line at Lough Foyle, of which so interesting an account has been given by Captain W. Yolland,[1] who for several years acted under him in his arduous duties. The compensation-bars have also been satisfactorily employed by Mr. Maclean at the Cape of Good Hope, in measuring a base of eight miles, in 1840-41; by Lieut.-Colonel Everest, for several base lines, in India;[2] and, by Captain Yolland, in the re-measurement, in 1849, of Major-General Mudge's base line, of about seven miles, on Salisbury Plain. The same principle of compensation was used in the preparation of some metal rods, to assist in the restoration of the standard-yard, after the destruction by fire of the Houses of Parliament, in October 1834.

The reproduction, by the electro-deposit process, of duplicates of the engraved plates, from which the maps are printed, instead of using and wearing out the original plates, was extensively employed for the maps of the Ordnance Survey, and the alterations, or additions required for the Geological Survey, were thus easily and inexpensively made. In fact, whenever any ingenious process, likely to facilitate labour, was brought under the notice of Colonel Colby, he examined it with the determination of using it, if it appeared at all feasible; and when any officers under his command made any useful proposition, he not only authorized the experiment, but, if successful, gave them the full merit of the work; indeed he was first to direct attention to the great abilities of Captain Drummond, afterwards Under-Secretary of Ireland, of Lieutenant-Colonel Larcom, now holding that important post, and of Lieutenant-Colonel Dawson (Assoc. Inst. C.E.), now at the head of the 'Copyhold Commission,' and he readily availed himself of the services of Lieutenant (now Lieutenant-Colonel) Portlock, R.E.,

---

[1] "An Account of the Measurement of the Lough Foyle Base, with its verification and extension by Triangulation;" published by order of the Board of Ordnance in 1847.

[2] "An Account of the Measurement of Two Sections of the Meridional Arc, in India;" by Lieut.-Colonel Everest, &c.; published in 1847.

who was intrusted with the observations for the principal triangulations in Ireland, (excepting those in the immediate vicinity of Lough Foyle,) and who also had charge of the secondary and minor triangulation, and of the computations for the supply of distances and altitudes, until he was appointed to conduct the Geological branch of the Survey, whilst its execution formed part of the duties of the officers of the Ordnance Survey in Ireland.

In addition to those officers who have been more particularly alluded to, the names of Lieutenant (now Major) Robinson, who was employed in settling the northern boundary line, on the frontiers of the United States, Lieutenant Murphy, who was engaged on the Euphrates expedition, under Colonel Chesney, and died after its successful termination, Lieut.-Colonel Mudge, Lieut.-Colonel A. W. Robe, Captain Bennett, and Major James (Assoc. Inst. C.E.), who has been recently appointed to superintend the Survey, should be mentioned, as having taken active part in the labours of Colonel Colby, and their devoted services and personal attachment to him were always a pleasant theme for his reminiscences.

In 1825 he was promoted to the rank of Lieutenant-Colonel, became Colonel in 1837, and Major-General in 1846, when, by the (much-to-be-regretted) rules of the service (first applied in his case), it was considered incompatible for him to retain his connexion with the great work he had so long and so ably directed, and with which his name will ever be most honourably associated.

He was one of the original Fellows of the Astronomical Society, and assisted in framing the rules for its government, at the period of its formation in 1820. He succeeded General Mudge, as a Member of the Board of Longitude; was a Fellow of the Royal Societies of London and Edinburgh; of the Geological, Geographical, and Statistical Societies of London; a Member of the Royal Irish Academy, and of the Geological Society of Dublin; an LL.D. of the University of Aberdeen, and a Knight of Denmark.

He became connected with this Institution, as an Associate, in 1820, and was transferred to the class of Honorary Members in the same year. He was much attached to many Members of the Society, very frequently attended the meetings, took

part in the discussions, was always ready to afford information, or assistance, and at every annual meeting, the Council had the pleasing task of recording General Colby's unceasing attention and liberality, in procuring for and presenting to the Library, the Ordnance Maps, and many other valuable documents, as soon as they were published.

The scientific services of General Colby are given, in considerable detail, in the Annual Reports of the Royal and the Astronomical Societies for 1852, and in a Memoir, worthy of its object, by Lieutenant-Colonel Portlock, published in the Professional Papers of the Corps of Royal Engineers, Vol. III., New Series, 1853. His life was a course of scientific research, and his name will hereafter be inseparably connected with the history of the Ordnance Survey. His character was distinguished for genuine simplicity and honesty, and his frank, open-hearted manner, and genial hospitality, created for him a host of friends, who loved and admired him; and at his decease, which occurred at New Brighton, Cheshire, near Liverpool, on the 2nd of October 1852, in the sixty-ninth year of his age, it might be said of him, that few men were more sincerely regretted.

Mr. JOHN GEORGE CHILDREN was born on the 18th of May 1777, at Ferox Hall, near Tonbridge, and received the early rudiments of his education at the grammar-school of that town, under the eyes of his father, a gentleman of considerable fortune and an active magistrate, whose life was devoted to the care of his only son. From thence he was removed to Eton, and in 1794, was entered a Fellow Commoner of Queen's College, Cambridge. He quitted the University in 1798, and went to Lisbon, where he stayed a few months, for change of scene, after a severe domestic affliction. In 1802, he sailed for North America, and, with his cousin, visited, not only the principal cities and towns in the United States, and in Canada, but penetrated far into the backwoods. His return to Europe was hastened by a violent attack of the lake fever; but on his arrival at home he entered the West Kent Militia, as one of its Captains; and served actively, until another severe fit of illness compelled him to resign his commission.

Henceforward his time and talents were directed to scientific

pursuits; Chemistry, Galvanism, and Mineralogy, chiefly occupying his attention, and amidst a circle of scientific men, composed of Davy, Hatchett, Wollaston, Leslie, and others, he soon occupied a distinguished position, granted to him for his knowledge and acquirements, and maintained by his uprightness, honesty of purpose, and amiability of character.

In 1807 he was elected a Fellow of the Royal Society, and to it, he communicated the results of the experiments in his laboratory at Tonbridge, and accounts of the two large plate Galvanic Batteries constructed by him, the two latter papers being published in the Philosophical Transactions.[1]

He made a journey to Spain, chiefly for the purpose of examining the quicksilver mines of Almaden, of which, at that period, but little was known, and there he acquired knowledge and practical experience, which eventually became valuable to him, for when, in consequence of the failure of a bank, at Tonbridge, in which his father was a partner, the family estate was sacrificed, Mr. Children immediately devoted himself to the practical application of his scientific acquirements, and being, at the same time, appointed one of the Librarians at the British Museum, he became fairly launched in the scientific world.

A little before that period, he was engaged in the controversy respecting the safety lamp, espousing warmly the cause of his friend Davy; and the paper on that subject published in 1816 in the Philosophical Magazine,[2] conveys a fair impartial statement of the question at issue.

After the decease of his father, who appears to have enjoyed, in a very high degree, the esteem and respect of the gentry of Kent and of his fellow townsmen of Tonbridge, Mr. Children took up his residence at the British Museum, having been transferred from the department of Antiquities to that of Natural History. He was also elected in 1826, and again in 1830, one of the Secretaries of the Royal Society, and increased his already wide circle of friends, by the urbanity he displayed in exercising the functions of this, at times, troublesome post, well meriting the unanimous vote of thanks offered to him, and

---

[1] Vide Phil. Trans., 1809, p. 32; and 1815, p. 363.
[2] Vide Philosophical Magazine, 1816, vol. xlviii. p. 189.

the warm eulogium passed on him by the President, on his resignation of the Secretaryship in 1837.

By degrees he became a Fellow, or Member of most of the Literary and Scientific Societies of this country, and received the Honorary Membership of several Foreign Societies; he was also the first President of the Entomological Society, in the establishment of which, he had exerted himself very successfully.

He was looked up to with considerable respect, as a chemical authority, and his evidence in cases of litigation, was frequently sought. In the celebrated case of Severn, King and Co.,[1] when the Lord Chief Justice Dallas, in allusion to the evidence of the scientific witnesses, who had been drawn up in martial and hostile array against each other, said, whilst admitting their talents, he lamented the sad discrepancy of their opinions and contradictory evidence, on points that should not have admitted of a doubt, he acknowledged, that Mr. Children's clear and well-considered views did him great honour. At this period (1818 to 1824) his life was one of considerable activity; he was one of the early editors of the Zoological Journal;—frequently contributed papers to other scientific periodicals; — published translations of "Thénard's Essay on Chemical Analysis," in 1819, and of "Berzelius' Treatise on the use of the Blowpipe," in 1822; and bringing his chemical knowledge to bear on his previous observations in Spain, he discovered a system of separating the silver from the ore, without the use of quicksilver, for which he received a moderate sum from the Mining Companies in South America, who might have realized great benefit from the discovery, but that they preferred paying him not to promulgate the process.

Mr. Children resigned his situation at the British Museum in the year 1839, and henceforth lived, chiefly, at the residence of his daughter, at Halstead, in Kent;[2] still occasionally visiting

[1] Vide "Report of the Trial of the Action, brought by Messrs. Severn, King and Co., against the Imperial Insurance Company, &c., on the 11th to 13th April, 1820." 8vo. London, 1820.

[2] Since the decease of Mr. Children, a very interesting memoir from the pen of his daughter, Mrs. J. P. Atkins, has been privately printed, and circulated among a few of his friends; it contains the principal events of his life, and some unpublished poetry by his father and himself; the Author regrets not having had cognizance of the existence of the work until the present slight sketch was in type.

the Metropolis, and mingling with the friends and associates of former years, with the same interest and kindly feeling as when he was actively engaged in similar pursuits.

He devoted the last few years of his life, chiefly to the study of astronomy, into which he entered with all the energy of his nature, and in the contemplation of the wonders of those realms to which he calmly awaited his removal, he drew his last breath, on the 1st of January 1852, in his seventy-fifth year, without a struggle; his latter hours being, like the whole of his mortal career, gentle, and full of peace and love towards all around him.

He was elected an Honorary Member of this Institution in the year 1838, and was ever ready to lend his aid for its benefit, as he was a great advocate for the closest intimacy between scientific men of all classes, and he justly regarded the labours of the Civil Engineer as connected with the useful practical application of all scientific investigations.

Mr. JOHN BARNES, who was born at Walker-Colliery, near Newcastle-upon-Tyne, on the 12th of August 1798, descended from a family of mining engineers; the five previous generations having all been "coal viewers," of considerable eminence in the north. His father, Thomas Barnes, (who died in the year 1801) was a man of education and general acquirements, and in a voluminous correspondence with Smeaton, and subsequently with Boulton and Watt, relative to the erection and duty of steam-engines, for draining mines and raising coals, erected under his direction, from their plans, he exhibited proofs of superior information on the subject of steam and its application, and demonstrated great sagacity and intelligence.

With such a father, and under the care of a mother, who was well calculated to guide and instruct him, from his earliest days, John Barnes was imperceptibly induced to study, and the plates of Dr. Desagulier's Natural Philosophy, became his hornbook and primer. At a very early age he was committed to the care of the Rev. W. Rawes, M.A., in whose school, at Houghton-le-Spring, Durham, he received the rudiments of a superior classical and mathematical education; his

predilection for mechanical construction manifesting itself, more powerfully than pleasantly, in his illustrations of the graphic descriptions in Cæsar's Commentaries, of Catapultæ, and Arbaletæ, with the models of which, made in his hours of recreation, he frequently endangered his companions and his tutors.

At the early age of fifteen he was removed from school, when, in consideration of the important services rendered by his father, to the firm of Boulton and Watt, and in consequence of the celebrated James Watt being his godfather, he was received into the Soho Works, and allowed access to all parts of the establishment, enjoying the advantage of frequent intercourse with the heads of the establishment, and receiving instruction from Murdoch, Southeron, and the other eminent men, then conducting the executive portions of the Soho Works. He there formed an intimacy with Mr. Joseph Miller, (M. Inst. C.E.) who ultimately became his partner, and during the period of his stay at Soho, his aptitude for acquiring knowledge, and his untiring industry in accumulating information, seizing only on the most essential points, with an intuitive dread of wasting time on trivialities, were remarkable features in the character of a youth not seventeen years of age.

In 1815, furnished with introductions from Mr. Watt, to Professors Playfair and Leslie, he went to Edinburgh, where he followed, with assiduity, the various classes, but more particularly those of Natural Philosophy, Mathematics, Chemistry, Mineralogy, Logic, and Drawing. Here he followed the same untiring course of study and, on quitting the university, he brought away high testimonials of the intelligence he had displayed, and for his successful mastery of subjects, to which he had devoted attention. From Professor Leslie, in particular, he obtained a letter, mentioning in terms of high commendation, the great proficiency he had attained in the study of natural philosophy, and stating that frequently, during the absence of the demonstrator, Mr. Barnes had performed the experiments, illustrative of the Professor's lectures.

On quitting Edinburgh, in the year 1817, Mr. Barnes was articled to the late Mr. F. Giles (M. Inst. C.E.), to receive instructions in surveying, and at the end of the year 1818, his master said of him, " He is now competent to the practice of

land surveying, levelling, and mapping, and as to his abilities, they are competent to anything he may follow."

Being then twenty years of age, he thought it was time to commence his professional career, and whilst looking around for an engagement with some established civil engineer, he received some employment for engineering and surveying business; among others from Messrs. Gordon and Murphy, who desired to engage his services at the mines of Moran, near Vera Cruz, for the purpose of superintending the erection of steam-engines, and for suggesting such improvements, as might seem to him best calculated to drain and work the mines effectually and economically. In consequence of some misunderstanding arising between the Mining Company and the Spanish Government, he renounced his intention of going to South America; but was commissioned by Messrs. Gordon and Murphy to design and superintend the construction of a pumping-engine on the Cornish principle; this machine he ordered at the Butterley Iron Works, where his former companion and friend, Mr. Joseph Miller, was then engaged, and being thus again brought together, an arrangement was entered into between them, to commence business in London, as manufacturing engineers, with the avowed object of devoting their attention principally to the construction of engines for steam-vessels. Accordingly in the year 1822 the firm of Barnes and Miller commenced the construction of engines, in which, from the beginning, they introduced the use of steam expansively in marine engines, a system not generally practised at that period; but to which, with general improved proportions and better workmanship, must be attributed, in a great degree, the success they attained and the reputation they established, both in England and on the Continent, but more especially in France, where in consequence of the shallowness of the water, and the rapidity of the currents in the principal rivers, the lightness and excellent proportions of the framing and other parts, the general efficiency, and the moderate consumption of fuel of their engines, were valuable points.

Before this period, the introduction of steam power for the propulsion of passenger vessels on the Rhone and the Saone, had been scarcely deemed practicable, and the endeavonr to employ it for towing barges, had been attended with very moderate suc-

cess. When attempted by some French Engineers, by Messrs. Manby, Wilson and Co., of Charenton, and by Messrs. Steele and Atkins, of La Gare, a member of this latter firm was killed by the explosion of the boiler, in an attempt to propel the vessel against the stream; and the Writer of this memoir (who had gone on board to aid his countrymen in overcoming a diffiulty,) only saved his life and those of his workmen, by ordering them in great haste from the boat, on perceiving that the working engineer had fastened down the safety valve, by a strut between the end of the valve lever and the deck carline; the explosion occurred, before the party reached the shore, and the unfortunate cause of it perished, with a number of persons of some importance in Lyons.

This catastrophe and the general indifferent success of the previous attempts, had so depressed all speculative enterprise at Lyons, that when a Company was formed, for the navigation of the Rhone, Messrs. Barnes and Miller felt themselves called upon to make a considerable investment in the affair, to impart to it some degree of confidence, which still was very wavering; when however, on the first upward voyage, intelligence was sent by courier, from each station, that the steamer was overcoming all difficulties, the value of the shares rose, as the solution of the problem approached, and when the boat reached Lyons, in two days less than the time guaranteed by the Engineers, the securities had reached a premium, and were eagerly purchased from Messrs. Barnes and Miller, who immediately secured extensive orders for engines and machinery for France, and subsequently for this country, where the reputation of the machinery from the works thus established, has been worthily maintained to the present time.

It should be mentioned, also, that the "Sophia-Jane," the first steam-vessel ever employed in Australia, was constructed by Messrs. Barnes and Miller, and was sent out to the colony, as their speculation.

At the termination of his connexion with Mr. Miller, in 1835, Mr. Barnes commenced business on his own account, giving the designs for the engines, for which he entered into contracts, and superintending their construction at the Horseley Iron Works, Tipton, near Birmingham. In this manner he supplied a number of engines, of acknowledged superiority, using an improved kind of feathering paddle-wheel, similar to "Cavé's,"

or "Morgan's" wheel, in the general features, but simpler and of a more solid and enduring construction. These engines and paddle-wheels were chiefly placed on board vessels constructed by the celebrated ship-builder, M. Normand, of Havre-de-Grace, and the success attained, was such as might have been anticipated, from the combination of the talents of two such men.[1]

Among the vessels so produced, was 'Le Napoléon,' in 1842, one of the earliest successful attempts to adapt the screw propeller to navigation; an account of which was given by M. Normand at a meeting of the Institution, on the 13th February 1844, and recorded in the Minutes of Proceedings.[2]

The following extract, from a communication from M. Normand, fils, gives an interesting account of some of Mr. Barnes' labours, and exhibits the high appreciation of his talents, and the feeling entertained for him in a foreign land:—

"Monsieur Barnes réunissait à la pratique de son art, une instruction et une érudition presque universels, qu'il est donné à peu d'hommes de posseder. Esprit calme et judicieux, il ne se livrait point témérairement aux nouveautés; mais il savait distinguer, avec une rare sagacité, les innovations heureuses, et toutes les fois qu'il les adoptait, c'était pour les ameliorer.

"C'est ainsi qu'en 1836, il reprenait les roues à aubes mobiles, alors discreditées, par les mauvais résultats qu'on en avait obtenu dans la pratique. M. Barnes avait si profondément et si habilement étudié la construction de ces roues, que du premier coup, il leur donna les proportions, et les dispositions générales les plus avantageuses, en même temps qu'il introduisait dans les details de leur construction, des améliora-

[1] During the connexion with M. Normand, the following vessels were produced:—

	H. P.		H. P.
Le Courrier	64	Brought forward . . .	924
Le Rotterdam	140	Une Étoile	70
Le Phœnix	160	Deux Étoiles	70
L'Amsterdam	160	L'Hercule	130
Le Castor	140	L'Alcide	130
Le Pollux	140	Le Calvados	70
Le Morlaisien	120	Le Napoléon	120
Carried forward . .	924	Total . . .	1514

[2] Vide Minutes of Proceedings, Inst. C.E., 1844, vol. iii. p. 79.

tions qui ont fait disparaître les objections qui jusques là en avait fait considérer l'application comme impraticable. Les travaux de M. Barnes, sur cette question, peuvent être considérés comme le point de départ de tout ce qui c'est fait depuis, dans cette voie, ou il a lui-même continué de marcher si largement; c'est à lui, sans contredit, qu'est due la généralisation de cet excellent propulseur.

" Profondément versé dans la delicate question, de la résistance des bâtiments, science aussi nécessaire à l'ingénieur, qu'au constructeur, il excellait à évaluer, à l'avance, la vitesse, et à déterminer, par suite, les proportions des roues.

" Réunissant, ainsi, au dégré le plus éminent, une instruction théorique supérieure, à une connaissance intime de la pratique de son art, il n'est point étonnant, que tous ses travaux aient été des succès brillants.

" En 1837, il construisit les machines, du ' Rotterdam,' du ' Phénix,' et de ' l'Amsterdam ;' en 1838, celles du ' Castor,' et du ' Pollux ;' ces deux derniers bâtiments étaient les plus rapides bateaux de mer, de leur époque, et malgré le temps, comparativement éloigné, ou plusieurs d'entre eux, ont été construits, ils soutiennent encore honorablement la comparaison avec des bâtiments modernes. En 1838, il construisit aussi, les machines des bateaux de rivière ' les Etoiles ;' et malgré les obstacles multipliées, que présentaient le peu de profondeur de la Seine, et le passage d'un grand nombre de ponts bas et étroits, qui imposaient des conditions extrèmement gênantes et défavorables, il parvint à faire des machines à action directe, dont la legèreté n'a guères été surpassée depuis ; les bateaux chargés obtinrent, dans les essais, une vitesse, en eau morte, de 11·6 neuds, soit 12·2 milles Anglais, vitesse probablement sans égale à cette époque. Il construisit, dans le même temps, les machines de ' l'Hercule,' et de ' l'Alcide,' les deux plus puissants rémorqueurs du Havre ; ces deux bateaux étant destinés exclusivement au rémorquage, M. Barnes disposa tout, — machines, chaudières et roues,—en vue de ce service spécial, et arriva, ainsi, à produire des machines qui donnent un effet utile, bien supérieur à la plupart des machines appliquées au rémorquage.

" Attentif au début de l'hélice, il comprit de suite les avantages de ce propulseur, et appréciant, avec la justesse de vues,

qui lui était propre, toute la portée et l'avénir de ce fait nouveau, il contracta en 1841, envers le Gouvernement Français, des engagements qui eussent été téméraires pour des hommes moins surs que lui; l'événement dépassa ses espérances; 'Le Napoléon' fut pendant plusieurs années, le plus rapide et le plus parfait bâtiment à hélice existant, et il est encore maintenant un des meilleurs bâtiments de la flotte Française."

"Dans notre tristesse, nous sommes heureux, de rendre ces témoignages, à la mémoire de celui que nous regrettons tous, et avec lequel mon père a si souvent partagés des succès."

For some time subsequently, Mr. Barnes was principally engaged as a consulting Engineer, as referee, in cases of litigation, and to some extent in designing marine engines; until the year 1845, when, through the recommendation of his friend Mr. Robert Stephenson, M.P., the management of the works at La Ciotat, near Marseilles, was intrusted to him by MM. Louis Benet and C$^{ie.}$, and where, in spite of impediments, which would have effectually arrested any man possessing less confidence in his own powers, or less determination to exercise them, he produced, entirely from his own designs and chiefly from drawings made by himself, a number of steam-vessels advantageously known in the Mediterranean,[1] where they perform the service of the Post-office, and on other stations.

On the completion of the 'Charlemagne,' screw steam frigate, his last, and probably, his most successful work, he received the decoration of the Légion d'Honneur, with a highly complimentary testimonial from the Government, for the services

---

[1] The principal engines constructed by Mr. Barnes, at La Ciotat, were for the following vessels:—

	H. P.		H. P.
Le Philippe Auguste	180	Brought forward	1210
L'Hellespont	180	Le Charlemagne (Vaisseau de ligne, à hélice)	450
Le Bosphore	180	L'Industrie	120
Le Courrier de Corse	120	L'Etna (remorqueur)	50
La Ville de Grasse	70	Le Dragueur	25
Le Bonaparte (à hélice)	120	Le Periclès	120
La Salamandre (à hélice)	120	En outre la machine, pour l'épuisement du bassin à Gènes	20
L'Ariel (à hélice)	120		
Le Progrès	120		
Carried forward	1210	Total	1995

rendered to France, in the improvement of her steam navy; services, which it is deeply to be regretted, could not have been secured for his own country, and which were not only offered, but were pressed on the Government, by those friends who knew Mr. Barnes' value, before he consented to accept the engagement at "La Ciotat."

Mr. Barnes was a man of profound and varied knowledge; in addition to the wide range of scientific subjects connected with his profession, in all of which he was soundly versed, he understood the most minute practical details of construction, indeed, he was frequently blamed for expending his valuable time, on minor points, which might have been intrusted to others. His recreation was the study of the early history of mankind, and he was deeply read in the antiquities of Egypt, Greece, and Rome, as well as in Architecture, Archæology, Numismatics, and Ethnology; he had devoted much attention to Theology, and entertained sound and original views of the correspondence between the Mosaic accounts of the Creation, and modern Geological investigations. He was a good Greek and Latin scholar, spoke and wrote French with great fluency, and for the purposes of aiding his studies had acquired several modern languages. He was a good executive musician, and was thoroughly versed in the theory of the science.

He was a sound and original thinker, and it was impossible to come in contact with him, without being struck by the philosophical character of his views, and being instructed by his conversation.

He joined the Institution, as a Member, in the year 1823,—frequently distinguished himself in the discussions at the meetings, imparting freely the rich stores of knowledge he possessed; and always mindful of its interests, he bequeathed to the Library a considerable portion of the correspondence of his father with Mr. Smeaton, and Messrs. Boulton and Watt, which it is anticipated may exhibit some interesting facts connected with the history of engineering at that period.

During the last few years of his life, he was subjected to severe trials in his professional career, which he was aided in supporting by the unfailing devotion of his excellent wife; a lady descended from the old Staffordshire families of Biddulph and Burnet, and who possessing most excellent sense and

talents, unobtrusively influenced her husband and supported him, under trying circumstances, when without such incitement his energies might have flagged. Her deep solicitude was for his welfare and happiness, as her sole ambition was to see his fame established; to the former she devoted her life, and the latter must be amply satisfied by the universal testimony of esteem and respect paid to his memory.

He died at La Ciotat, on the 24th of September 1852, in the fifty-fourth year of his age, after a very short illness; his remains were brought to England by his only brother, and laid beside those of his parents, at Long Benton, near the place of his birth.

He was an upright, honest man, who used well the talents he had been blessed with, and he carried with him, to the grave, the esteem and respect of all who knew him.

Mr. DAVID BREMNER, the second son of Mr. James Bremner, M. Inst. C.E., was born at Wick, Caithness-shire, on the 14th February 1818. Whilst at school he exhibited great steadiness and assiduity, and a decided inclination for the studies most necessary for the profession he subsequently adopted. He then devoted himself to the acquisition of the theory and practice of surveying, and among his first mechanical efforts were some ingenious improvements in cranes used in harbour-works. Upon one of these works, the completion of the harbour of Keiss, Caithness (in 1833), for which his father had the contract, David Bremner may be said to have commenced his active career. In 1834 he was transferred to the works at Sarclett, four miles south of Wick, another contract taken by his father, where the proprietor, aided by the Fisheries Board, had vainly attempted to raise a structure for sheltering the fishing-craft; but the violence of the waves had baffled all the constructive skill and power, of those who preceded Mr. Bremner. By the united skill and perseverance of the father and son, the work was brought to a satisfactory termination, and in 1835, David Bremner, still acting under his father, was chiefly intrusted by him with the execution of the works, designed by him, for the new harbour of Lossiemouth, the port of Elgin, in Morayshire. Here he was very successful, in the methods of damming out

the water from the excavations in the rocks, whilst in progress, in spite of the furious onslaught of the waves of the North Sea, to which the works were fully exposed. His coolness in difficulty, his ingenuity in devising means for executing the work, together with his perseverance and determination, impressed all, with whom he was brought into contact, with very favourable opinions of his qualifications.

With the object of giving him experience in other branches of the profession, he was then placed under the late Mr. John Gibb (M. Inst. C.E.), of Aberdeen, and was by him employed at the erection of the Victoria Viaduct, over the Weare, at Beddick, Durham. Thence he removed, in 1839-40, to Granton, Edinburgh, where, at the new pier, he enjoyed the advantage of the experience and instructions of Mr. Howkins (Assoc. Inst. C.E.), by whom he was engaged as Assistant, and at the end of 1840, Messrs. Walker and Burges, the Engineers-in-chief for those works, kindly admitted him into their office in London, where he remained until his father required his aid, in 1842, in the construction of the harbour at Pittulie, in Aberdeenshire.

In 1844 he was intrusted by Mr. Simpson (V.P. Inst. C.E.), with the direction of the new Harbour and Dock-works at West Hartlepool, Durham, where he remained, until a vacancy occurred, under the Trustees of the River Clyde and Harbour of Glasgow, when he was elected, in a flattering manner, to the position of Resident Engineer, and, aided by his brother Alexander, performed the duties with great credit, until his premature decease, on the 14th March 1852, in the thirty-third year of his age, generally regretted as a promising engineer, who, if he had been spared, would have attained a good position in the profession.

He joined the Institution, as an Associate, in 1842, and became a Member, by transfer, in 1851. During his residence in London he attended the meetings very regularly, and the part he took in the discussions indicated the practical nature of his professional education.

Mr. ROBERT BRUNTON was born at Lochwinnoch, North Britain, on the 10th of February 1796, and at fourteen years of age was received as a clerk in the cotton mills, at that place;

but when, in 1812, those works were destroyed by fire, he went to Belfast, and on the introduction of his brother, Mr. John Brunton, C.E., was engaged at the foundry of Messrs. Chain and Young, whence he transferred his services to Messrs. Claude Girdwood and Co., Glasgow, where he compiled his "Compendium of Mechanics,"[1] a valuable text-book for Engineers, and one of the first of a most useful class of publications for practical men; in the latter years of his life he devoted some time to the preparation of a new edition of this work, which it is hoped may soon be published.

About the year 1823 he arrived in London, and acted for some time as chief assistant and draughtsman to his brother, the late Mr. William Brunton, C.E., but on the removal of that gentleman to South Wales, he was engaged by Messrs. Banks and Co., of Bilston, Staffordshire, in whose works he obtained the first insight into the manufacture of iron, in all its branches. He then became the principal assistant of Mr. Isaac Dodds, (M. Inst. C.E.) at the Horsley Iron Works, Staffordshire, and aided in perfecting several of his ingenious mechanical inventions and improvements.

In 1835 he entered the service of the Indian Iron Company, and as their chief Engineer, constructed and managed the works at Porto Novo, on the coast of Coromandel, East Indies. His reports on the manufacture of iron and steel in India, and the observations recorded during his journeys in France, Spain, Germany, Norway and Denmark, are full of information, and demonstrate the talent for observation which was one of the distinguishing features of his character. The failure of his health obliged him to return to England, but his connexion with the Indian Iron Company, continued at intervals, until the period of his decease, which occurred at the Maestaeg Iron Works, Glamorganshire, of which he was the acting Engineer.

Mr. Brunton joined the Institution, as a Member, in the year 1842, and during his residence in London was a very constant attendant at the meetings, taking an active part in the discussions. He was a man of great quickness of perception,

---

[1] "A Compendium of Mechanics," containing practical rules and tables, connected with the Steam-engine, Water-wheel, Force-pump, and Mechanics in general; also examples for each rule, calculated in common decimal arithmetic." By Robert Brunton. 8vo, plates. Glasgow, 1824.

possessed a considerable fund of theoretical and practical information, and had profited by the opportunities he had enjoyed of gaining experience. He was a kind-hearted, amiable person, with an amenity of manner which won the confidence of all with whom he was brought into contact, and his decease on the 6th of July 1852, in his fifty-sixth year, caused a void in a social circle, where his remembrance will long be cherished.

SIGNOR TOMMASO CINI was born in 1812, at San Marcello, in the Tuscan Apennines, where his family have long held a high position, amongst the large landed proprietors of the district. He early exhibited a predilection for mechanical pursuits, and was educated at the University of Pisa, with a view to his adopting the profession of an Engineer. About the year 1832 he was engaged in building and establishing, on the family property, a large paper mill, in which, amongst his numerous avocations, he continued to be deeply interested until the period of his decease. Between 1842 and 1845, he was engaged as Architect and Engineer, in the construction of an extensive woollen factory, and of two large establishments for smelting copper, besides supplying many architectural, mechanical, and civil engineering designs, and was consulted in most of the new industrial undertakings of Tuscany. In 1845 he completed the surveys for a railroad across his native mountains, from Pistoja, into the Bolognese territory; an undertaking presenting many difficulties, in preparing for which, and in mastering all obstacles, he exhibited great skill and talent; the most striking qualities of his mind being a wonderful facility in resources, united to untiring energy and application. The necessary concession, for the Apennine railroad, being obtained from the Government, by him and his brothers, the Company was formed and the capital subscribed, when the political crisis of 1848 put an end to the undertaking, and the Company was dissolved.

In 1847, Signor Cini passed three months in England, visiting the most important engineering works connected with the railroads, and on his return to Italy, he was induced by a private Company, to make a survey for a line between Rome and the Neapolitan frontier; whilst occupied on this project,

the revolution broke out at Milan, and Signor Cini immediately joined the Italian forces, in Lombardy. A commission in the Corps of Engineers was given to him, and he served, with great energy and distinguished courage, through all the unfortunate campaign; at Curtatone, Casal Maggiore, and Brescia, gaining the approbation of his commanding officer, and the goodwill and esteem of his comrades.

Italy being once more brought into a state of tranquillity, Signor Cini returned to his civil occupations, and on the death of the Engineer-in-chief of the line of railroad, then in course of construction, between Lucca and Pistoja, he was selected by the Company to fill the vacant post, and he constructed that part of the line between Pescia and Pistoja. He still did not lose sight of his favourite project, of connecting the Adriatic with the Mediterranean by a railroad across the Apennines; and in 1851, when the different governments of Central Italy began to entertain the idea of uniting, to construct a line between Parma, Modena, Bologna and Tuscany, Signor Cini wrote a small work entitled "Sui passi che presenta l'Appenino Toscano, per una via ferrata," and when the construction of the line was decreed and the Company was formed, he was appointed the chief Engineer of the whole line from Reggio and Modena, across the mountains, to Pistoja.

Just at this moment, when everything appeared propitious towards the execution of the undertaking, to which he had devoted such an amount of energy and of valuable time,—when nothing remained, but to obtain the ultimate ratification of the contracts between the Governments and the Company, for which purpose he made a journey to Modena, his strength failed, the excessive mental and bodily exertion he had undergone, had irrecoverably shattered his frame, and he died on the 25th of June 1852, (only the day before the last contracts were to have been signed,) in the fortieth year of his age, regretted by his country, beloved and esteemed by his friends and all who knew him.

He joined this Institution on the 29th of June 1847, as a Member, but his constant occupations in Italy precluded his attending the meetings, or contributing the original communications which he had promised.

Mr. WILLIAM TIERNEY CLARK was born at Bristol, on the 23rd of August 1783. By the premature decease of his father, young Clark was deprived of the advantages of a full course of education, and he owed his eventual position in life entirely to unremitting attention to his duties, and to his determination to avail himself of every opportunity for self-improvement. He was apprenticed, at an early age, to a millwright at Bristol, and having, whilst serving his time, availed himself of all occasions, rare as they were at that period, of acquiring scientific and practical knowledge, he, on being engaged at the Coalbrook Dale Iron Works, soon became a good practical mechanic. Not, however, content with the mere practical part of his profession, all his leisure hours were devoted to studying the higher branches of science, and thus his services were soon rendered so valuable to his employers, that he was, at an early period of his career, intrusted with the superintendence of important works.

The Coalbrook Dale Foundry was celebrated for having produced the first iron bridges erected in England, from the designs of Telford and Jessop; and in that establishment, where he remained until the year 1808, he gained great experience, in the application of cast and wrought iron.

At that time Mr. Rennie, who, in the substitution of cast-iron for other materials, in the great works executed by him, visited every important foundry, and knew every rising man, offered him a situation at his works in Holland-street, Blackfriars, which, with the assent of his employers, he gladly accepted, and thus was at once removed, from comparative obscurity in the country, to a sphere of extended action under an eminent engineer, whose confidence he enjoyed to such an extent, that he encouraged the commencement of that intimate connexion and private friendship between his sons and Mr. Clark, which only terminated with the decease of the latter.

Under Mr. Rennie he was engaged on several large works, and in 1811 he was recommended by his employer, for the post of Engineer to the West Middlesex Waterworks, at that period, though five years after its creation, still a very insignificant establishment, with one pumping-engine of 20 H.P., a small reservoir, barely sufficient to contain one day's supply for the neighbouring straggling hamlet of Hammersmith, and with

a capital of only £20,000, upon which no dividend had ever been received. By unremitting attention, judicious extension of the works, and increasing the capital, as the westward emigration from the City converted fields and gardens into streets and squares, he lived to see the works increased, under his direction, to an aggregate engine power of 245 horses, reservoirs capable of containing about 40,000,000 gallons, and of furnishing nearly one-tenth of the requisite supply of the metropolis, with a capital of £700,000, and an annual rental of nearly £70,000.

During the progress of these labours he executed some interesting works; such as the large engines, and the main of pipes across the Thames, at Hammersmith, with the reservoirs, and filter-beds, &c., at Barnes, and was, with the consent of his employers, extensively engaged as a consulting Civil Engineer.

The first public work upon which he was actively engaged, was the Thames and Medway Canal, which presented considerable difficulties of execution, particularly in the tunnel between Gravesend and Rochester; they were, however, successfully overcome, and the canal proved of essential service in shortening the navigation, until, in the course of events, in 1844, a line of rails was laid on a timber viaduct, partially covering the canal through the tunnel, and eventually, the channel was filled up, and appropriated for the rails, on which the rapid locomotive superseded the sluggish canal-boat.

His next work, in order of execution, was the Hammersmith Suspension Bridge, commenced in 1824 and finished in 1827. This bridge is somewhat remarkable for the small deflection of the chains, the span between the points of suspension being 422 feet 3 inches, and the versed sine only 29 feet 6 inches. It exhibits some originality in the careful forging and boring of the links, the turning of the pins, the trussing of the platform, and the good proportions of the piers.

He then completed the Suspension Bridge at Marlow, which had been commenced in 1829 by Mr. Millington, his predecessor as Engineer to the West Middlesex Works.

The Suspension Bridge over the Arun, erected for the Duke of Norfolk, near Shoreham, then occupied his attention, and is a favourable specimen of his architectural taste and knowledge of proportion.

He also designed and erected a handsome cast-iron bridge at Bath, and a smaller one, of the same material, near Windsor.

In the Gravesend Town Pier, erected under his directions in the short space of thirteen months, from the passing of the Act in 1834, he carried into effect more fully the principles he had imbibed under Mr. Rennie, of substituting iron for other materials, wherever it was practicable. The circumstances of the violent opposition to the erection of this landing pier, which was the first of the kind on the Thames, where they are now so numerous, and yet still so ill-adapted for the accommodation of the multitudes who pass over them, are detailed in the Transactions of this Institution, with full details of the structure.[1]

The most important work undertaken by Mr. Clark, was the Suspension Bridge over the Danube, to unite Pesth and Buda, in Hungary. This magnificent structure has been recently well described in a work[2] published under Mr. Clark's directions. It contains the origin and progress of the undertaking, with translations of the Reports of Count George Andrásy and Count Stephen Széchenyi, and other documents, with details of the whole work, which was commenced in 1839 and was finished in 1849, at a cost of £622,042.

Mr. Clark says of it, "Thus was finished Pesth Suspension Bridge, a work which, in its construction, encountered probably more difficulties than any structure of a similar kind in existence; the magnitude of the river over which it is thrown, its depth, the nature of its bed, and the velocity of the current, created misgivings, at one time almost universal in Hungary, that no permanent communication could ever be established across the Danube, between Buda and Pesth.

"The moral difficulties to be overcome, no less than the physical obstacles, were very great; pride, prejudice, and jealousy had each to be encountered, so universally against the object at one period, that nothing less than the extraordinary energy and perseverance shown by Count Széchenyi could have withstood their evil effects, and few would have made the attempt."

[1] Vide Trans. Inst. C.E., vol. iii. page 245; 4to. London, 1842.

[2] Vide "An Account, with illustrations, of the Suspension Bridge across the River Danube," &c., by W. Tierney Clark, F.R.S. 8vo. Plates. Weale. London, 1852-3.

On the completion of the Pesth Bridge, the Emperor of Austria presented to Mr. Clark, through the Archduke Charles, a snuff-box, set with brilliants, as a token of his approbation of the work, and of the mode of its construction. Its stability has been signally demonstrated, not only by its withstanding the shocks of the masses of ice brought against the piers, by the torrent of the Danube, but whilst yet in a comparatively incomplete state, by its being subjected to bombardment; its bearing the alternate and repeated charges of an attacking army, and the tumultuous crowding of a retreating force, as well as its even resisting the attempts of the military Engineers to destroy it by gunpowder.

The physical difficulties recorded in the volume, which has been mentioned, and which were perhaps greater than in any similar work, were encountered and overcome by Mr. Clark and his assistants, with an amount of skill, energy, and perseverance, which reflects honour, not only upon them individually, but upon the whole of the profession, and is another instance of the noble manner in which English Engineers can and do perform their duty.

The Emperor of Russia also, in 1845, presented to Mr. Clark a gold medal of the first class, for a design for a suspension bridge across the Neva, at St. Petersburgh.

He was frequently consulted on other engineering works, and for some time, previously to his decease, had been engaged on the works for supplying Amsterdam with water; but his favourite branch of the profession was bridge-building, and in that he attained a high reputation, and it is to be regretted that his failing health, for a long period, prevented his undertaking many large works, which would have been worthily executed by him.

Mr. Clark was a Fellow of the Royal and of several other Societies; he was a very old Member of this Institution, having been elected in 1823. He served on the Council, and contributed an original communication;[1] and whenever he attended the meetings, which, however, was much less frequently than could have been desired, he took an active part in the discussions.

---

[1] Vide Transactions, Inst. C.E., vol. iii. p. 245. London, 1842.

He was a man of refined taste and elegant pursuits, of much originality of design, and careful consideration of the details of his plans, which the practical character of his early life enabled him to lay down with great minuteness. His professional career was not one of excitement, and he was particularly fortunate in his undertakings. He was universally respected by his brother Engineers, and his decease, which occurred on the 22nd of September 1852, in his sixty-ninth year, after a lingering illness, caused deep regret to a large circle of attached friends.

Mr. FRANK FORSTER was born in the year 1800, in the neighbourhood of Newcastle-upon-Tyne, and was placed at an early age with Mr. Fenwick, to learn the business of a colliery viewer, or mining agent. After some years, so spent, in that district, he was intrusted with the management of some extensive mining works, near Swansea, and subsequently was engaged in a similar capacity in Lancashire. While in this employment, about the year 1830, he made the acquaintance of Mr. Robert Stephenson (M.P., V.P.), then embarking in the arduous undertaking of the London and Birmingham Railway, who at once perceived in him the precise qualities for a valuable assistant. Thenceforth they became intimate friends, and Mr. Forster was at the right hand of his chief, both in the severe parliamentary struggle, to obtain the Act of Parliament and in the more congenial professional duty of carrying that Act into execution. The section of the work confided to Mr. Forster's immediate superintendence, included the Kilsby Tunnel, and the Blisworth Cutting, and in these difficult and novel services, his energy and skill were conspicuous. He continued, from that time, to be the trusted associate of Mr. Robert Stephenson in his chief enterprises, up to the completion of the Chester and Holyhead Railway, on which he was the Resident Engineer of the portion from near Conway to Holyhead, embracing all the masonry and the general arrangements of the Britannia Bridge, besides the troublesome tunnels, sea-walls and other works, through the Welsh hills and ravines and along the coast.

During this period of his career, an Engineer of sound expe-

rience being required for the examination of an important coal-field, near Richmond in Virginia, United States, on the joint recommendation of Mr. R. Stephenson and the late Mr. Buddle, (M. Inst. C. E.) the well-known mining Engineer, Mr. Forster was selected, and he performed the task with which he was intrusted in a masterly manner and with all the energy of his nature; indeed it may be remarked, that mining was, to the last, his favourite pursuit.

He was, however, soon to move on a more public scene of usefulness. On the formation of the Metropolitan Commission of Sewers, he was, under the highest auspices of the profession, unanimously appointed Chief Engineer to that body, and forthwith entered on the laborious duties of the post. This is not the place to detail the prejudices that had to be encountered, the contending interests to be conciliated, the acrimony to be submitted to, the interferences to be put up with, and even the slanders to be refuted. All these he bore, outwardly, with his habitual equanimity, although his sensitive nature keenly felt the sting; but his good sense convinced him, that much allowance was to be made, for the impatience of a public long and often disappointed of improvements, which they had been almost taught to believe could be effected at a blow, and for the jealousies of those, whose importance had been suspended, or whose projects were not at once adopted. A little more kindliness out of doors, and a more general and hearty support from the Board he served, might have prolonged a valuable life, which as it was, became embittered and shortened, by the labours, thwartings, and anxieties of a thankless office. Worn out by annoyances, Mr. Forster resigned his appointment, and died a few weeks afterwards. His reports and plans for the general drainage of London, north of the Thames, remain on record, and of his talents and acquirements in his profession, the estimation in which he was generally held must be the best evidence. The characteristics of our deceased friend were clearsightedness, integrity and disinterestedness in professional matters, and combined with these he disclosed, in private life, a character, simple, truthful and affectionate; to which rare qualities were added the resources of a well-stored memory, and the refinements of a cultivated literary taste.

His decease occurred suddenly on the 13th of April 1852,

in his fifty-second year; and when his remains were consigned to the tomb, in Highgate Cemetery, they were met by a large number of his professional brethren, who had spontaneously resolved thus to demonstrate their sense of the public and private virtues of their deceased friend, and by the erection of a monument, to exhibit their heartfelt sympathy for the premature loss of so good and talented a man.

He was not an old member of the Institution, having only been elected in 1845, and his engagements, being chiefly in the country, precluded his giving much personal attendance at the meetings, but he took part in some discussions in so able a manner as to cause regret that he could not more frequently be present.

Mr. THOMAS GRAINGER, of Craig Park, Mid-Lothian, was born on the 12th of November 1794, at a farm, then tenanted by his father, at Gogar Green, Ratho, near Edinburgh, and in the classes of the University of that city his education was completed.

At sixteen years of age he entered the office of Mr. John Leslie, who enjoyed some reputation, at Edinburgh, as a Land Surveyor, and on quitting that position, after six years of active labour, he commenced business on his own account in 1816, as a Civil Engineer and Surveyor, and soon obtained considerable employment in laying out and improving public roads.

About the year 1823, when railways, as means of conveyance, were first brought before the public, Mr. Grainger conceived a very just view of their probable importance, and strongly advocated their adoption, chiefly for the purposes of the mineral districts; this probably influenced the survey of the Monkland and Kirkintilloch railway being confided to him, and when, in 1824, the Act of Parliament had been procured, the execution of the line was intrusted to him. This railway is stated to have been the first, in Scotland, on which 'edge rails' were used, and it proved to be so good an investment, that it induced the construction in the same district, of the Ballochney, and the Glasgow and Garnkirk lines, in 1826, and of the Wishaw and Coltness railway in 1829.

In the year 1825, Mr. Grainger entered into partnership with Mr. Miller (M. Inst. C. E.), and the engineering works were executed, under their joint superintendence. The success of the Liverpool and Manchester line gave a fresh impetus to railway speculation, which extended to Scotland, and induced in 1830 the proposition for a line between Edinburgh and Glasgow, for which Messrs. Grainger and Miller acted as joint Engineers; the application to Parliament was not however successful, and soon afterwards, although they continued in partnership, it was arranged, that so far as Engineering was concerned each should execute his own works.

In 1834 Mr. Grainger executed the Paisley and Renfrew railway, and in 1835, the Arbroath and Forfar line; he laid out the Glasgow and Greenock railway in 1836, but ceased to be connected with it after the passing of the Act for its construction. In that year he also laid out and subsequently executed, the Edinburgh, Leith and Newhaven line, and projected a harbour at Trinity, between Leith and Granton, which aided in determining His Grace the Duke of Buccleuch, to the execution of his great undertaking, the new harbour at Granton, for which Mr. Walker (M. Inst. C. E.) was the Engineer.

The connexion with Mr. Miller was dissolved in 1845, and in the busy period which immediately followed, Mr. Grainger was occupied upon many enterprises in Scotland, among which may be mentioned, the Edinburgh and Bathgate, and the Edinburgh, Perth and Dundee railways, in connexion with which latter, he designed and executed the harbours at Broughty Ferry, and at Ferry-Port-on-Craig, where for facilitating the transport of the railway traffic across the Tay, he contrived a steam barge to receive on its deck a train of waggons, for the loading and unloading of which some very ingenious plans were adopted, which were described in a paper read before the Royal Scottish Society of Arts, in 1848.

In England also, Mr. Grainger had considerable employment, chiefly on the Leeds, Dewsbury and Manchester, on the East and West Yorkshire Junction, and the Leeds Northern railways, on the latter of which were some considerable works, such as the Morley and the Bramhope Tunnels, and the Wharfe Viaduct, the latter consisting of twenty-one segmental arches, each 60 feet span, built on a curve of 2,500 feet radius, crossing

the river at a very considerable height, and forming an important feature amidst the surrounding beautiful scenery.

In this brief sketch, only the principal works in which he was engaged have been mentioned, but enough has been stated to show the position he held in the profession, and the selection of him to fill the Chair of the Royal Scottish Society of Arts, for two successive years, and the deference paid to his views, by his coadjutors, in the Town Council of Edinburgh, of which he was a member, mark the general estimation in which he was held. For the former body, he was strenuous in his efforts to extend its utility, and set an excellent example to the members of that and other societies, by making a journey to Holland, for the express purpose of drawing up an account, from personal inspection, of the draining operations at Haarlem Meer, to be read during the first year of his Presidency.

He distinguished himself as a useful citizen of Edinburgh, devoting, in his latter years, much of his time to the affairs of the city, with great benefit to the community.

He possessed strong common sense, great perseverance and determination of purpose, combined with simplicity of mind, and in the social and domestic relations of life, he was most amiable and exemplary. At his decease, which occurred in his fifty-eighth year, on the 25th of July 1852, in consequence of injuries received in a collision of trains, at the junction of the Clarence, with the Leeds Northern Railway, near Stockton-on-Tees, he was regretted as a firm friend, a kind master, and a sincere, consistent Christian.

He joined the Institution as a Member, in the year 1829, was constant in his attendance at the meetings, whenever he visited the Metropolis, and studiously advanced the interest of the Society by every means in his power.

MR. WALTER HUNTER was born in the parish of Newbattle, near Edinburgh, in the year 1772, and from his father, who was a "wright," combining the trade of a carpenter with the construction of the rude agricultural machinery of that period, he learned the first rudiments of the craft, in which he subsequently became a greater proficient, whilst in the employment of Messrs. Moodie, of Leith-walk, who had then a considerable business as millwrights. By that firm he was

sent, at about twenty years of age, to erect a threshing-mill in the neighbourhood of Nottingham, and being attracted by the fame of the Soho Works, he was so fortunate as to be engaged by Mr. Watt, and worked under him for some time. From Soho he went to London, and obtained employment under the late Mr. Rennie, by whom he was intrusted (as foreman) with the direction of several important works.

When the attention of the mercantile world was directed to the importance of providing a greater extent of accommodation for the increasing shipping, the necessity for some better mechanical means of clearing away accumulations of mud in tidal docks, and of shoals formed in rivers, became evident, and Mr. Hunter was sent by Mr. Rennie, to examine and report upon a dredging-boat, which was supposed to have been the first machine of the kind introduced from Holland, and then working, with horse-power, in the river Humber, at Hull. The result of this mission was the adaptation, by Mr. Rennie, of steam-power to move the dredging-buckets and ladders, and the ultimate introduction of that branch of millwright's work, on which Mr. Hunter was eventually so extensively engaged, in the establishment of dredging-vessels, on the Thames and elsewhere.

On the completion of the Phœnix Oil and Flour-mills, at Dartford, where he acted as foreman of works under Mr. Rennie, Mr. Hunter commenced business on his own account at Dartford, as a millwright, but there was, at that period, so little employment for mechanics, that he was obliged again to become a journeyman; and he used to relate, as an example of the difference of engineering, at the beginning and the termination of his career, and of how much depended on the skill and experience of the foreman of works, that the only drawing he received for the erection of the Phœnix Mills was a rough sketch of the first frame for the moving power, all the details of the machines, the connexions, and the modifications of speed, &c., being left to be filled in by the foreman, during the progress of the work.

In 1807, or 1808, he entered into partnership with the late Mr. William English, and founded the establishment at Bow, where the machinery for so many important works has been executed.

The connexion between Messrs. Hunter and English arose

from their being intrusted by Mr. Rennie to frame a pair of large lock-gates for the East India Docks, which task they performed in such a style as to attract the attention of Mr. Ralph Walker, by whom they were subsequently employed, until they entered into business on their own account, when he intrusted to them a great amount of work, to which they did full justice.

They were extensively employed in the distilleries and breweries of the metropolis, in the numerous mills around London, in the construction of sluices, valves for water supply, iron bridges, dock-gates, &c.; and the excellence of their workmanship, their mechanical skill, and general uprightness of conduct, induced the confidence of the heads of the profession and the formation of a business, by which a large fortune was amassed by both partners.

Mr. Hunter was a very old member of the Institution, having joined it in 1827, but his occupations seldom permitted his attendance at the meetings. His decease occurred on the 8th of February 1852, in the eightieth year of his age,—deeply regretted by all who knew him,—and in him disappears almost the last of the race of clever English millwrights.

Sir JOSIAH JOHN GUEST, Bart., M.P., was born at Dowlais, on the 2nd of February, 1785.

His grandfather, Mr. John Guest, the son of a small freeholder in Shropshire, migrated in the middle of the last century to South Wales, and in connexion with Mr. John Wilkinson, the celebrated iron-master of Bircham, they together erected at Dowlais, the first blast-furnace in the Principality, for the reduction of iron-ore, by means of pit-coal. After the decease of Mr. John Guest, the works passed into the hands of a firm, of which his son, Mr. Thomas Guest, was a member. In 1815, Sir John (then Mr.) Guest succeeded to the sole management, and the works, which in 1806 were considered of importance, because they produced about 5,000 tons of iron, were by the skill, perseverance and commercial enterprise of the subject of this memoir, raised in their annual power of production to 100,000 tons of pig-iron, and actually produced that quantity in 1849, when they sent into the market 75,000 tons of iron in the form of bars and rails.

Sir J. John Guest received his education principally at the Grammar School of Bridgenorth, Shropshire; the early part of his career was closely devoted to the direction of the Dowlais Iron Works, and becoming thoroughly conversant with the details of the manufacture of iron, he was fully alive to the improvements to be introduced, by a proper application of chemical and engineering knowledge, and many scientific men and members of this Institution visited the works, in furtherance of his views of ameliorating the various processes. He tried improved blowing-engines, the substitution of raw coal for coke in the furnaces, and the use of hot-blast, with many minor alterations. He was one of the first iron-masters who undertook to roll the present heavy rails, the manipulation of which was for some time deemed nearly impracticable, and generally he spared no expense, or labour in perfecting the machinery and the processes.

The influence derived from the number of persons employed and the capital invested, joined with the general appreciation of his strong good sense and business habits, induced his return to Parliament in 1826 for the borough of Honiton, and after the passing of the Reform Bill, he represented the newly-created borough of Merthyr Tydfil, from 1832 to the period of his decease.

Although strict in enforcing subordination among the multitude of men in his employment, he was ever watchful for their interests, and sought their spiritual and temporal benefit in every way; founding places of worship, and establishing schools, whilst, during periods of mercantile depression and the visitation of disease, his charity was unbounded, and in these labours of love he was ably seconded by his wife, the Lady Charlotte Elizabeth Bertie, only sister of the Earl of Lindsey. This estimable lady, whose literary powers are as well appreciated as her general talents and acquirements in branches of knowledge not usually presenting attractive features for ladies, appears to have felt, that on arriving among a dense population of hitherto ill-educated people, speaking a peculiar dialect, and isolated by their habits and manners, few of the inhabitants of Dowlais having ever travelled twenty miles from their homes, she was called to a task of no little importance, to which she lent all the powers of her mind: she

acquired the language, she visited the homes, she administered to the wants of all around her; and in thus performing her Christian duties, she extended the previously-acquired influence and power of her husband. That this influence was considerable, and was used for the good of the men, was well shown at the time of the Merthyr riots in 1831, where, but for his mediation between the men and his brother iron-masters, it is very probable that the loss of life would not have been confined to the rioters who were shot by the military, on the first outbreak of the disturbances.

For some years past, although retaining the Dowlais Works entirely in his own hands, Sir John Guest had, in consequence of failing health, chiefly resided at Canford Manor, Dorset, which he had adorned with many specimens and curiosities, brought from Nineveh by Lady Charlotte Guest's relative, Mr. Layard, M.P.; he however, had a great love for his early home, and his latest desire was to draw his last breath among the scenes of his childhood; where he was born and lived he desired to die and be buried. He breathed his last on the 26th of November 1852, in his sixty-eighth year, and was followed to the grave, not only by a great number of the resident gentry of the county, and by his numerous agents and household, but by thousands of the working class, who, by their demeanour, showed how deeply they felt the loss of their benefactor and friend.

Sir John Guest received the title of Baronet in 1838; whilst his health permitted, he was very assiduous in his attention to his Parliamentary duties, and it was chiefly owing to his exertions, that the borough of Merthyr obtained the privilege of returning a Member. He joined the Institution as an Associate in 1834, and in its welfare, as in that of other scientific societies, he took considerable interest.

Mr. JOHN SYLVESTER (born at Sheffield, October the 24th, 1798) was the son of Mr. Charles Sylvester, the Author of "The Philosophy of Domestic Economy, 1819,"[1] in which

[1] "The Philosophy of Domestic Economy," by Charles Sylvester. 8vo. 1819.

work were detailed the results of the first attempts to reduce to a system, the application of science and engineering skill to domestic arrangements. His successful application of the new principles to the Derbyshire Infirmary, and the numerous works of a similar nature, subsequently executed under his direction, have conferred on him an enduring fame; he was also a good mathematician and chemist,[1] and by the unreserved communication of his ideas, frequently aided in the development of the plans of other scientific men and Engineers, with whom he was intimate; thus it is said, that his favourable opinion of the merits of the proposed system of construction, of the Liverpool and Manchester Railway, tended to confirm Mr. George Stephenson's views, and to encourage him in their prosecution.

The example of the father, and the practical instruction conveyed to the son, who was connected with him in business, could not fail to induce the same ardour in scientific pursuits, and eventually Mr. John Sylvester became very successful in the execution of large works, for warming and ventilating buildings, to which he specially applied his scientific knowledge, and constructive skill; and which he extended, also with advantage, to the improvement of many of the most ordinary domestic arrangements, as for instance, in the "radiating stove-grate," of which he presented a specimen to the Library of this Society.

He was very successful in the arrangement of the apparatus, for preserving an equable and temperate atmosphere, on board the Arctic Discovery Ships, and Captains Parry, Ross, and others, ascribe the health of the crews, in a great degree, to the excellence of the system he prescribed.

He was a man of original views and great determination, which frequently led him to do more than was required, or was calculated for his own interest, and a novel application, or an unforeseen difficulty to be overcome, had charms for him, to which the greatest ordinary success appeared tame.

He possessed considerable knowledge of horticulture, and in the grounds of Mr. Strutt, M.P., at Kingston Hall, near Derby, he erected some forcing-houses and vineries, about the year 1844, which were very successful, and where, it is stated,

---

[1] He was author of "An Elementary Treatise on Chemistry." By Charles Sylvester. 8vo. 1809.

he used a ridge and furrow roof and a double gutter bar, very similar to, if not identical with, those which formed such important features in the construction of the Crystal Palace in 1851. A similar mode of roofing was also adopted by him, in 1850, for the vineries erected for Mr. Francis Wright, of Osmaston Manor.

He was a man of studious habits, and was a good amateur artist; his drawings and etchings exhibiting considerable power, and his love of retirement and for wandering in the country, gave a mild and placid tone to his communications with all around him. He suffered, for some considerable period, from a very unusual and painful complaint, an accumulation of "hydatids" on the liver, to an extent perhaps scarcely ever before recorded, and he died on the 16th of August 1852, generally regretted as a good man and a valuable member of society.

He was a member of several scientific societies, at whose meetings he was a frequent attendant; he joined this Institution as an Associate in the year 1828, and was ever ready to forward its interests in every way.

Mr. Henry Vint was born in London in the year 1778, and after receiving his education at the Soho School, under Dr. Barrow, entered into business as a shawl manufacturer, in which, however, he did not long continue; but being in possession of ample means, he frequently visited the Continent, and resided at Naples for nearly six years, cultivating that taste for the fine arts which induced him, eventually, to make the collection of pictures, bronzes, and antiquities, &c., which, at his decease, he liberally bequeathed to the town of Colchester, where he had fixed his residence. He took a very active part in the public affairs of that town, was twice elected Mayor, and in acknowledgment of the services he rendered, in procuring the erection of the new town-hall, he was presented with a valuable piece of plate by his townsmen.

Mr. Vint joined the Institution as an Associate in the year 1838, and frequently attended the meetings, being much attached to mechanical pursuits. He was the inventor of a submerged paddle-wheel for steamers, for which he took out

patents, and of which he exhibited the model at the last conversazione, only a few weeks before his decease, which occurred suddenly, on the 22nd of June, 1852, in the seventy-fourth year of his age, universally regretted by all who had the good fortune to enjoy his acquaintance.

Mr. HENRY CHARLES RAWNSLEY was elected a Graduate of this Institution on the 21st March 1840, and his decease is supposed to have occurred in the year 1852; but all attempts to procure any particulars of his professional career have been fruitless.

PREMIUMS AWARDED.

Session 1851-52.

The Council of the Institution of Civil Engineers have awarded the following Premiums:—

1. A Telford Medal, in Silver, to Captain Mark Huish, Assoc. Inst. C. E., for his paper "On Railway Accidents."
2. A Telford Medal, in Silver, to Braithwaite Poole, Assoc. Inst. C. E., for his paper "On the Economy of Railways."
3. A Telford Medal, in Silver, to Colonel Samuel Colt (U. S. America), Assoc. Inst. C. E., for his paper "On the Application of Machinery to the Manufacture of Rotating Chambered-breech Fire-arms, and the peculiarities of those Arms."
4. A Telford Medal, in Silver, to Frederick Richard Window, Assoc. Inst. C. E., for his paper "On the Electric Telegraph, and the principal improvements in its construction."
5. A Telford Medal, in Silver, to Charles Coles Adley, for his paper entituled "The History, Theory and Practice of the Electric Telegraph."
6. A Telford Medal, in Silver, to Eugène Bourdon (Paris), for his "Description of a new Metallic Manometer, and other Instruments for measuring Pressures and Temperatures."
7. A Telford Medal, in Silver, to Pierre Hippolyte Boutigny (d'Evreux), for his "Description of a new Diaphragm Steam Generator."
8. A Telford Medal, in Silver, to George Frederick White, Assoc. Inst. C. E., for his "Observations on Artificial or Portland Cement."
9. A Council Premium of Books, suitably bound and inscribed, to John Baldry Redman, M. Inst. C. E., for his paper "On the Alluvial Formations, and the Local Changes, of the South-Eastern Coast of England, from the Thames to Portland."

10. A Council Premium of Books, suitably bound and inscribed, to William Thomas Doyne, Assoc. Inst. C. E,, and to Professor, William Bindon Blood, for their paper, entituled "An Investigation of the Strains upon the Diagonals of Lattice-Beams, with the resulting Formulæ."
11. A Council Premium of Books, suitably bound and inscribed, to George Donaldson, Assoc. Inst. C. E., for his paper, "On the Drainage and Sewerage of the Town of Richmond (Surrey)."
12. A Council Premium of Books, suitably bound and inscribed, to Professor Christopher Bagot Lane, Assoc. Inst. C. E., for his "Account of the Works on the Birmingham extension of the Birmingham and Oxford Junction Railway."
13. A Council Premium of Books, suitably bound and inscribed, to William Bridges Adams, for his paper, "On the Construction and Duration of the Permanent Way of Railways in Europe, and the modifications most suitable to Egypt, India, &c."

SUBJECTS FOR PREMIUMS.

Session 1852-53.

The Council invite communications on the following, as well as other subjects, for Premiums:—

1. On the Principles upon which the Works for the Improvement of River Navigation should be conducted, and the effects of the works upon the Drainage and Irrigation of the District.
2. The construction, improvement and maintenance of Natural, or Artificial Harbours and Docks, with the forms and action of large Sluices, for clearing away deposits, by the use of Backwater, or by directing the natural Currents.
3. The selection of Sites for the construction of Docks, on the course of Tidal Streams, with reference to communication with Railways, and with Inland Navigation.

4. The selection of Sites for, and the principles of, the construction of Breakwaters and of Harbours of Refuge; illustrated by examples of existing works.
5. The forms and construction of Piers, Moles, or Breakwaters, (whether solid, or on arches,) Seawalls, and Shore Defences; illustrated by examples of known construction, such as the Cobb Wall at Lyme Regis, &c.
6. The best system of forming Artificial Foundations, showing the ratio of pressure to surface, and the soil best calculated to sustain heavy structures; illustrated by the best examples in modern practice, and by accounts of the failures of large works.
7. The relative value of various kinds of Natural Stone, available in Great Britain for the purpose of construction; with experiments on the law of increase of the crushing force, of short blocks of stone, with their diameters.
8. On Brick and Tile Making, and the capability of introducing new forms for Engineering and Architectural purposes. With the processes most useful to Emigrants and Settlers.
9. The laws of the Strength of Cast and Wrought Iron, under the various conditions of Tensile, Compressive, Transverse, Tortional, Impulsive, and other Strains; with examples illustrative of the co-efficients employed by eminent practical authorities, in the construction of works.
10. The construction of Girder Bridges, whether of Trussed Timber, or Wooden Lattice; of Cast Iron, trussed, or plain, or combined with Wrought Iron, in simple, or compound triangulation; of Wrought Iron Lattice work; or of plate iron riveted sides, with cellular top and bottom.
11. The construction of Suspension Bridges with Rigid Platforms, and the modes of Anchoring the Stay Chains.
12. The comparative advantages of Iron and Wood, or of both materials combined, for the construction of Steam Vessels, with drawings and descriptions;—the methods for preventing corrosion;—and details of the arrangements for the Compasses in Iron Ships.

13. On the changes that have been introduced, within the last fifteen years, in the Lines of Ships and Steam Vessels; and an examination of the effects produced by the new Law of Measurement for Tonnage.
14. An examination of the circumstances which appear to limit the maintenance of higher speeds, than are now attained by Steam Ships in deep-sea navigation; and an inquiry into the causes which have hitherto prevented the asserted high speeds of Steam Navigation, on the American Rivers, from being arrived at in England.
15. The best method of External Condensation, so as to permit the employment of Salt, or of Hard Water, and furnishing Pure Water for the Boiler; with a description of various systems of Evaporating, Refrigerating, &c.
16. The results of the use of Tubular Boilers, and of Steam at an increased pressure, for Marine and other Engines, noticing particularly the difference in weight and speed in proportion to the Horse Power, and the Tonnage; with details of the most successful means for avoiding Smoke in Furnaces of all descriptions.
17. The best methods of reducing the temperature of the Engine and Boiler room of Steam Vessels, and of preventing the danger arising from the over-heating of the base of the funnel.
18. The relative efficiency of the Screw Propeller and Paddle Wheels, when applied to vessels of identical form, tonnage, and steam power, independent of the use of sails.
19. The results of the application of Steam Power and Screw Propellors to the conveyance of Coal, as compared with the system of Sailing Vessels.
20. The arrangement and distribution of the Workshops at the principal repairing station of a Railway, for the repairs and maintenance of the Locomotives, Passenger, and other Carriages, &c.
21. The construction of Locomotive Engines, specially adapted for steep inclines; with accounts of experiments demonstrating the comparative value of large and small Engines, under various circumstances.

22. Improvements in the construction of Railway Carriages and Waggons, with a view to the reduction of the gross weight of passenger trains. Also of Railway Wheels, Axles, Bearings, and Breaks; treating particularly their ascertained duration and their relative friction.
23. The results of a series of observations on the flow of Water from the Ground, in any large districts, with accurately-recorded Rain Gauge Registries, in the same locality, for a period of not less than twelve months.
24. The conveyance and distribution of Water for the Supply of Towns; the sources from whence it may be derived, noticing the relative permeability of different rocks and soils, and their actual capacity for retaining and delivering water; a description of the different modes of collecting and filtering; and an account of the advantages, or disadvantages of the high-service constant-supply system, with notices of the best forms of large valves, and of the best methods of jointing pipes of large diameter, to resist considerable pressure, and the precautions to be observed in laying the mains through mining districts, where the ground is liable to sink.
25. The comparative duty performed by the various descriptions of Steam Engines for raising Water, for the Supply of Towns, or for the Drainage of Mines; noticing the depth and length of the underground workings, the height of the surface above the sea, the geological formation, the contiguity of streams, &c.
26. The Drainage and Sewerage of large Towns; exemplified by accounts of the systems at present pursued, with regard to the level and position of the outfall, the form and dimensions of the sewers, the prevention of emanations from them, the disposal of the sewage, whether in a liquid, or solid form, and of the arrangements for connecting the house drains with the public sewers.
27. On Warming and Ventilating Buildings.
28. The Precautions adopted for guarding against Accidents by Fire-damp in Mines.

29. The results of contrivances for facilitating the driving of Tunnels, or Drifts in Rock.
30. Descriptions of the various kinds of Machinery in use in the principal Shipping Ports, for the shipment of Coal; noticing particularly those, in which the greatest expedition is combined with the least amount of breakage of the Coal; and also accounts of the means of unshipping, and measuring or weighing the Coal on its arrival in port.
31. Descriptions of the Ovens, and of the best processes used in Great Britain, and on the Continent, in the manufacture of Coke for Railway and other purposes; with the comparative values of the products.
32. Improvements in the system of Lighting by Gas; the results of the use of Clay Retorts,—of large Ovens (for producing a better quality of Coke)—of Exhausters, Condensers, and modes of Purifying, and the precautions for the economical distribution of Gas.
33. A Mathematical, or Geometrical demonstration of the advantages of Flat Sails for Ships, over those of different degrees of curvature, when exposed to direct and slanting winds; with practical examples.
34. On the Application of Machinery, combined with Mechanical Power, and the means of transporting manure and produce, on large Farms and Agricultural Establishments; and on improvements in the plan of the works and buildings, and the 'plant' employed.
35. The most effective arrangement and form of Centrifugal and Reciprocating Blowing Apparatus.
36. The Chemical Analysis, and the application to economic purposes, of the Gases generated in Iron Blast Furnaces.
37. An investigation of the causes of "Red-" and of "Cold-Shortness" in Malleable Iron, and other Chemical Characteristics which affect the Physical Properties of Cast, or of Wrought Iron.
38. Description of Cast, or Wrought Iron Cranes, Scaffolding and Machinery, employed in large works, in Stone Quarries, Hoists, or Lifts on Quays, in Warehouses, &c., especially where either Steam, or Water is used as a motive power.

39. The various Systems of preserving Timber from decay, and from the attacks of marine insects, or the white ant.
40. On the Improvements which may be effected in the Buildings, Machinery, and Apparatus for producing Sugar from the Cane, in the Plantations and Sugar Works of the British Colonies, and the comparison with Beet-root, with regard to quantity, quality, and economy of manufacture.
41. Description of the Machinery adapted for the preparation of Indian Cotton.
42. Improvements in Flax Machinery, and in the processes for preparing the Flax for manipulation.
43. Notice of the principal Self-acting Tools employed in the manufacture of Engines and Machines; also of Moulding Machines and Wood-working Machines; and the effect of their introduction.
44. On the best system of remedying the inconvenience resulting from the present Want of Uniformity between the Weights, Measures, and Coins of the different countries of Europe.
45. The construction of Lighthouses; their Machinery and Lighting Apparatus; with notices of the methods in use for distinguishing the different Lights.
46. Memoirs and accounts of the Works and Inventions of any of the following Engineers:—Sir Hugh Middleton, Arthur Woolf, Jonathan Hornblower, Richard Trevithick, William Murdoch (of Soho), and Alexander Nimmo.

Original Papers, Reports, or Designs, of these, or other eminent individuals, are particularly valuable for the Library of the Institution.

The communications must be forwarded, on or before the 30th of January 1856, to the house of the Institution, No. 25, Great George Street, Westminster, where copies of this paper, and any further information may be obtained.

CHARLES MANBY, *Secretary.*

25, *Great George Street, Westminster,*
July 31*st*, 1852.

NOTICE.

It has frequently occurred, that in Papers which have been considered deserving of being read and published, and have even had Premiums awarded to them, the Authors may have advanced somewhat doubtful theories, or may have arrived at conclusions at variance with received opinions. The Council would, therefore, emphatically repeat, that the Institution must not, as a body, be considered responsible for the facts and opinions advanced in the Papers, or in the consequent Discussions; and it must be understood, that such Papers may have Medals and Premiums awarded to them, on account of the Science, Talent, or Industry displayed in the consideration of the subject, and for the good which may be expected to result from the discussion and the inquiry; but that such notice, or award, must not be considered as any expression of opinion, on the part of the Institution, of the correctness of any of the views entertained by the Authors of the Papers.

EXTRACTS FROM THE MINUTES OF COUNCIL, FEB. 23rd, 1835.

"The principal subjects for which Premiums will be given, are—

"1st. Descriptions, accompanied by Plans and explanatory Drawings, of any work in Civil Engineering, as far as absolutely executed; and which shall contain authentic details of the progress of the Work. (Smeaton's Account of the Eddystone Lighthouse may be taken as an example.)

"2ndly. Models, or Drawings, with descriptions of useful Engines and Machines; Plans of Harbours, Bridges, Roads, Rivers, Canals, Mines, &c.; Surveys and Sections of Districts of Country.

"3rdly. Practical Essays on subjects connected with Civil Engineering, such as Geology, Mineralogy, Chemistry, Physics, Mechanic Arts, Statistics, Agriculture, &c.; together with Models, Drawings, or Descriptions of any new and useful Apparatus, or Instruments applicable to the purposes of Engineering or Surveying."

INSTRUCTIONS FOR PREPARING COMMUNICATIONS.

The communications should be written in the impersonal pronoun, and be legibly transcribed on foolscap paper, about thirteen inches by eight inches, the lines being three-quarters of an inch apart, on the one side only, leaving a margin of one inch and a-half in width on the left side, in order that the sheets may be bound.

The Drawings should be on mounted paper, and with as many details as may be necessary to illustrate the subject, and should be to such a scale that they may be clearly visible, when suspended on the walls of the Theatre of the Institution at the time of reading the communication, or enlarged Diagrams may be sent for the illustration of any particular portions.

Papers which have been read at the Meetings of other Scientific Societies, or have been published in any form, cannot be read at a Meeting of the Institution, nor be admitted to competition for the Premiums.

EXCERPT BYE LAWS, SECTION XIV., CLAUSE 3.

"Every Paper, Map, Plan, Drawing, or Model presented to the Institution, shall be considered the property thereof, unless there shall have been some previous arrangement to the contrary, and the Council may publish the same in any way and at any time they may think proper. But should the Council refuse, or delay the publication of such paper, beyond a reasonable time, the Author thereof shall have a right to copy the same, and to publish it as he may think fit, having previously given notice in writing to the Secretary of his intention. No person shall publish, or give his consent for the publication of any communication presented and belonging to the Institution, without the previous consent of the Council."

ORIGINAL COMMUNICATIONS,

DRAWINGS, PRESENTS, &c.,

RECEIVED BETWEEN JUNE 30, 1851, AND JUNE 29, 1852.

ORIGINAL COMMUNICATIONS.

AUTHORS.

Adams, W. B. No. 866. The construction and the duration of the Permanent Way of Railways in Europe, and the modifications most suitable to Egypt, India, &c. With twenty-eight Diagrams.

Adley, C. C. No. 867. The Electric Telegraph; its history, theory, and practical applications. With twenty-two Diagrams.

Bourdon, E. No. 860. Description of a new Metallic Manometer, and other instruments for measuring pressures and temperatures. With eleven Diagrams.

Boutigny, P. H. (d'Evreux). No. 874. Description of a Diaphragm Steam Boiler.

Colt, Colonel S. No. 862. On the application of machinery to the manufacture of Rotating Chambered Breech Fire-arms, and the peculiarities of those arms. With a series of Diagrams.

Donaldson, G. No. 869. An Account of the Drainage of the Town of Richmond, Surrey, under the authority of the Metropolitan Commissioners of Sewers, in 1851.

Doull, A. No. 878. On a proposed railway communication, from the Atlantic to the Pacific, through the territories of British North America. With a Map.

Dundonald, Lord. No. 871. On the Results of the use of Tubular Boilers, or of flue boilers, of inadequate

AUTHORS.

surface, or imperfect absorption of heat. With one Diagram.

Huish, Captain, M. No. 877. Railway Accidents: their cause and means of prevention. Detailing particularly the various contrivances which are in use, and have been proposed; with regulations of some of the principal lines.

Jee, A. S. No. 865. Description of a Cast-iron Viaduct erected at Manchester, forming part of the joint station of the London and North-Western and Manchester, Sheffield, and Lincolnshire Railways. With four Diagrams.

Leslie, J. No. 872. Description of a design for an inclined plane, for conveying Boats from one level of a canal to another, by taking them over a summit, so as to obviate the necessity of using gates, or sluices, and to avoid any expenditure of water. With four Diagrams.

Pole, W. No. 861. Description of the Prismatic Clinometer; a new pocket instrument for measuring vertical angles.

Poole, B. No. 875. The Economy of Railways as a means of transit, comprising the classification of the traffic, in relation to the most appropriate speeds, for the conveyance of passengers and merchandize.

Richardson, J. No. 868. The Pneumatics of Mines. The amount of Ventilation required in collieries, determined by an investigation into the chemical properties of atmospheric air, and the noxious gases found in mines.

Russell, J. S. No. 873. On certain points in the construction of Marine Boilers.

Shaw, C. No. 864. Some observations on the principal Coal and Mineral Fields of Scotland.

White, C. F. No. 876. Description of the Locomotive Repairing Shops of the York, Newcastle, and Berwick Railway at Newcastle-upon-Tyne. With five Drawings.

AUTHORS.

White, G. F. No. 870. Observations on Artificial Hydraulic, or Portland Cement; with an account of the testing of the brick beam, erected at the Great Exhibition, Hyde Park.

Window, F. R. No. 863. On the Electric Telegraph, and the principal improvements in its construction. With twenty-two Diagrams.

ORIGINAL DRAWINGS.

DONORS.

White, C. F. Nos. 4607-11. Plans and Elevations of the Locomotive Repairing Shops of the York, Newcastle, and Berwick Railway, at Newcastle-upon-Tyne.

CATALOGUE OF PRESENTS.

BOOKS.

DONORS. TITLE OF WORK.

Airy, G. B. Results of the Astronomical observations made at the Royal Observatory, Greenwich. 4to. 1850.

——— Results of the Magnetical and Meteorological observations, made at the Royal Observatory, Greenwich, 4to. 1850.

[Extracted from the Greenwich Observations, 1850.]

Akademie der Wissenschaften. Abhandlungen der mathematisch-physikalischen classe der Königlich-bayorischen. Volumes 4 to 6. 4to. Plates. München, 1844-51.

——— Bulletin der, fur 1849-50-51. 4to. München, 1849-51.

Architectural Quarterly Review, The. Vol. I. No. 1. 8vo. Cuts. London, 1851.

Babbage, C. The Exposition of 1851; or, views of the industry, the science, and the government of England. By C. Baggage. 2nd edition. 8vo. London, 1851.

——— Observations on the Temple of Serapis at Pozzuoli, near Naples; with an attempt to explain the causes of the frequent elevation and depression of large portions of the earth's surface, in remote periods, and to prove that those causes continue in action at the present time. With a supplement. And conjectures on the physical condition of the surface of the moon. By C. Babbage. 8vo. Plates and Cuts. London, 1847.

——— On the influence of signs, in mathematical reasoning. By C. Babbage. Tract, 4to. Cuts. Cambridge, 1826.

Bain, A. A short history of electric clocks, with explanations of their principles and mechanism, and

DONORS. TITLE OF WORK.

instructions for their management and regulation By A. Bain. Tract, 8vo. Cuts. London, 1852.

Beardmore, N. Hydraulic Tables, to aid the calculation of water and mill power, water supply, and drainage of Towns, and improvement of navigable rivers. By N. Beardmore. 8vo. Plates. London, 1852.

——— Hydraulic and other tables, for facilitating calculations daily required by an engineer, with an appendix of Tide Tables. By N. Beardmore. 8vo. London, 1851.

——— The Nautical Almanac and Astronomical Ephemeris for the years 1852-53-54. 8vo. London, 1849-51.

Beechy, Captain F. W., R.N. Report of observations made upon the tidal streams of the English Channel, and the German Ocean, by order of the Lords Commissioners of the Admiralty, in 1848, 1849, and 1850, with explanatory charts and tables, giving the direction of the stream in all parts of the English Channel and North Sea, at every hour of the tide, flood and ebb. By Captain F. W. Beechy, R.N. Tract, 4to. London, 1851.

[Excerpt Philosophical Transactions for 1851.]

Beke, C. T. A summary of recent Nilotic discovery. By C. T. Beke. Tract, 8vo. London, 1851.

[Read before the British Association for the Advancement of Science, July 4, 1851.]

——— An inquiry into M. Antoine d'Abbadie's journey to Kaffa, to discover the source of the Nile. By C. T. Beke. Tract, 8vo. 2nd edition. Map and Cuts. London, 1851.

——— On the Alluvia of Babylonia and Chaldea. By C. T. Beke. Tract, 8vo. London, 1839.

[Excerpt the London and Edinburgh Philosophical Magazine, and Journal of Science for June, 1839.]

Bell, Jacob, M.P. Pharmaceutical Journal and Transactions. Vols. I. to XI. 8vo. Cuts. London, 1842-52.

Blackwell, T. E. Expériences hydrauliques, sur les lois de l'écoulement de l'eau à travers les orifices rectan-

DONORS. TITLE OF WORK.

gulaires verticaux à grandes dimensions, entreprises à Metz. Par M. Poncelet et Lebros. 4to. Plates. Paris, 1832.

[Memoire lu à l'Académie des Sciences, le lundi 16 Novembre, 1829.]

Board of Admiralty. Lune Navigation. Report relative to the works executed under the authority of the Lords Commissioners of the Admiralty, for the improvement of the navigation of the River Lune. By Messrs. Stevenson. Tract, 8vo. Plate. Edinburgh, 1851.

Bourne, John. A Treatise on the Screw Propeller. By John Bourne. Parts 1 to 11. 4to. Plates. London, 1851-52.

Bow, R. H. A Treatise on bracing, with its application to bridges and other structures of wood or iron. By R. H. Bow. 8vo. Plates and Cuts. Edinburgh, 1851.

Bramah, Messrs. The Bramah Lock Controversy. Tract. 8vo. London, 1851.

[Extracts from the Press.]

Bridgeman, H. O. Handbuck der Mechanik. Mit Beiträgen von neuern englischen Konstruktionem vermehrt und herangegeben von Franz Anton Ritter von Gertsner. 3 vols. 4to. Folio Atlas of Plates. Prag, 1832-33-39.

British Association for the Advancement of Science. Report of the twentieth meeting of,—held at Edinburgh, in July and August, 1850. 8vo. Plates and Cuts. London, 1851.

Brodie, R. Encyclopædia Metropolitana; or, Universal Dictionary of Knowledge, on an original plan, comprising the twofold advantage of a philosophical, and an alphabetical arrangement, with appropriate engravings. Edited by the Rev. E. Smedley, M.A. Second Division. Mixed Sciences. Vol. II. Plates. London, 1830.

Cadiat et Oudry, MM. Notice sur l'emploi de la Tole du

DONORS. TITLE OF WORK.

fer forgé, et de la fonte dans les Ponts. Par MM. Cadiat et Oudry. Tract, 8vo. Plates. Paris, 1851.
[Extrait de l'Annuaire de la Société des anciens Elèves des Ecoles nationales des Arts et Métiers.]

Cambridge Philosophical Society, Transactions of. Vol. IX. Part 2. 4to. Cambridge, 1851.

Chadwick, E. Reports to the General Board of Health, on a preliminary inquiry into the sewerage, drainage, and supply of water, and the sanitary condition of the inhabitants of the different cities, towns, boroughs, &c., in England. 8vo. Plates and Cuts. London, 1849-51.

———— General Board of Health. Minutes of information, collected on the practical application of sewer water and town manures, to agricultural production. 8vo. Cuts. London, 1852.

Chappell, Captain, R.N. Royal Mail Steam Packet Company Investigation. Minutes of evidence taken before a Committee, appointed to examine witnesses in London and Southampton, relative to the loss by fire, of the steam ship Amazon, on the morning of Sunday, the 4th January, 1852. Tract, 8vo. London, 1852.

Clark, D. K. Railway Machinery; a treatise on the mechanical engineering of railways, embracing the principles and construction of rolling and fixed plant, in all departments. By D. K. Clark. Parts I. to IX. Folio. Plates. Edinburgh, 1851-52.

Clegg, S. Jun. Lectures on Architecture; delivered at the College for General Practical Science, Putney, Surrey. By S. Clegg, Jun. 4to. Plates and Cuts. No place, or date.

Colding, A. An examination of steam-engines and the power of steam, in connection with an improvement of steam-engines. By A. Colding. Tract, 8vo. Copenhagen, 1851.

Combes, C. Récherches théoriques et expérimentales sur les roues à réaction ou à tuyaux. Par C. Combes. Tract, 4to. Plates. Paris, 1843.

DONORS. TITLE OF WORK.

Commission. Report of the Government Commission, on the chemical quality of the supply of water, to the Metropolis. Tract, 8vo. London, 1851.

Coxworthy, F. Electrical condition applied to facts connected with heat, crystallization, meteorology, evaporation, magnetic condition of the earth, gravitation, chemical affinity, respiration, ventilation, constitution of the atmosphere, agriculture and geology. By F. Coxworthy. Tract, 8vo. London, 1848.

——— Government; its uses and abuses. By F. Coxworthy. Tract, 8vo. London, 1852.

Dalrymple, G. S. Physiological Chemistry. By Professor C. G. Lehmann. Vol. I. Translated from the second edition, by George E. Day, M.D. 8vo. London, 1851.

[Printed for the Cavendish Society.]

——— Handbook of Chemistry. By L. Gmelin. Translated by H. Watts. Vol. VI. Metals concluded. London, 1852.

[Printed for the Cavendish Society.]

Darbyshire, G. C. Tables for setting out curves for railways, &c., with appendix containing demonstration and rules. By G. C. Darbyshire. Tract, 4to. Cut. Derby, 1846.

De la Beche, Sir H. Memoirs of the Geological Survey of Great Britain, and of the Museum of Practical Geology in London. Vols. I. and II. 8vo. Plates and Cuts. London, 1846-48.

——— Museum of Practical Geology and Geological Survey. Records of the School of Mines and of Science, applied to the Arts. Vol. I., Part 1. Inaugural and introductory lectures to the courses for the Session 1851-52. 8vo. London, 1852.

Dempsey, G. D. The machinery of the nineteenth century, illustrated from original drawings, and including the best examples shown at the Exhibition of the

DONORS. TITLE OF WORK.

Works of Industry of All Nations. By G. D. Dempsey. Parts I. to IV. 4to. Folio Plates. London, 1851-52.

Department of Practical Art. Letter, dated March 10, 1852, addressed to the Right Hon. J. W. Henley, M.P., President of the Board of Trade, &c., &c., by the Superintendents of the Department of Practical Art —accompanying the estimates of the year 1852-53, and laid before Parliament. Tract, 8vo. London, 1852.

Dupuit, J. Etudes théoriques et pratiques, sur le mouvement des eaux courantes, suivies de considérations relatives aux régimes des grandes eaux, aux debouchés à leur donner, et à la marche des alluvions dans les rivières à fond mobile. Par J. Dupuit. 8vo. Plates. Paris, 1848.

Ecole des Mines. Annales des Mines, ou recueil de mémoires sur l'exploitation des mines, et sur les sciences et les arts qui s'y rapportent ; rédigées par les Ingénieurs des Mines. 8vo. 4th Series. Vols. XII. to XX. Plates and Cuts. Paris, 1847-51.

Ecole des Ponts et Chaussées. Recueil des programmes des cours professés à l'Ecole des Ponts et Chaussées, pendant les sessions 1847-48 et 1848-49 ; précédé de quelques explications sommaires, sur le système général d'enseignement de cette Ecole. 4to. Lithographed.

———————— Conférences sur les irrigations, le drainage, le dessèchement des marais, la fixation des dunes et autres travaux analogues ; précédées de l'exposé des principes généraux de l'industrie agricole. M. Nadault de Buffon. 4to. Plates. Lithographed. Session 1849-1850.

———————— Suites des conférences sur les irrigations, les dessèchements de marais et autres travaux analogues. M. Nadault de Buffon. 4to. Plates. Lithographed. Session 1850-51.

DONORS. TITLE OF WORK.

Ecole des Ponts et Chaussées. Notes prises, par les elèves aux conférences sur les machines à vapeur locomotives. M. Clapeyron. Lithographed. 1850.

——————————— Notes prises au cours de Ports de mer. M. Frissard, Professeur. 4to. Avec cahier de planches. Lithographed. Session 1848-49.

——————————— Cours de droit administratif. M. Cotelle, Professeur. Lithographed. 1847-48.

——————————— Notes prises, par les elèves au cours de Construction des Routes. M. Bommari, Professeur. 4to. Plates. Lithographed. 1848.

——————————— Notes prises, par les elèves au cours de Navigation Intérieure. M. Mary, Professeur. 4to. Plates. Lithographed. 1850.

——————————— Cours de Géologie, appliquée aux constructions. M. Bayle, Professeur. 4to. 2nde Partie. Map and Cuts. Lithographed. 1850.

——————————— Explication des planches de fossiles, qui accompagnent le cours lithographié de Géologie, par MM. Dufrénoy et Emile Bayle 4to. Plates. Lithographed. 1847.

——————————— Notes sur le cours d'Hydraulique. M. Belanger, Professeur. 4to. Cuts. Lithographed. Session 1849-50.

——————————— Cours de Minéralogie, appliquée aux constructions. M. Dufrénoy, Professeur. 4to. Plates and Cuts. Lithographed. 1847.

——————————— Notes sur la mécanique appliquée aux principes de la stabilité des constructions, et à la théorie dynamique des machines. M. Belanger, Professeur. 4to. Cuts. Lithographed.

English, H. The Mining Manual and Almanack for 1851, being a yearly compendium of information on general science, with tabular, and other statistical

DONORS. TITLE OF WORK.

details, relating to the mining interests. By H. English. 8vo. London, 1851.

Fairbairn, W. An experimental inquiry into the strength of Wrought-iron Plates and their riveted joints, as applied to Ship-building, and vessels exposed to severe strains. By W. Fairbairn. Tract, 4to. Plates and cuts. London, 1850.

[Excerpt Philosophical Transactions for 1850.]

———— On the relative Powers of the Locomotive Engine, and the resistance of railway gradients. By W. Fairbairn. Tract, 8vo. Manchester, 1851.

[Excerpt Memoirs of the Manchester Literary and Philosophical Society, Vol. IX.]

———— Two lectures, on the construction of Boilers, and on Boiler Explosions, with means of prevention, delivered before the Leeds Mechanics' Institution, April 23 and 24, 1851. Also a paper on the consumption of Fuel and the prevention of Smoke, read before the British Association for the advancement of Science. By W. Fairbairn. Tract, 8vo. Plates and Cuts. Leeds, 1851.

Förster, C. F. L. (of Vienna). Allgemeine Bauzeitung, mit Abildungen. By C. F. L. Förster. 4to. Folio Atlas of Plates. Heft 3 to 10. Wien. 1850-52.

Franklin Institute, Journal of. Vols. XX. and XXII., Parts 1 to 5. 8vo. Cuts. Philadelphia, 1851.

Galloway, J. A. Communication with India, China, &c. Observations on the proposed improvements in the Overland Route *viâ* Egypt, with remarks on the ship canal, the Boulac canal, and the Suez railroad. By J. A. Galloway. Map. Tract, 8vo. London, 1844.

Geological Society of Dublin; Journal of. Vols. I., II., III., and V. 8vo. Plates and Cuts. Dublin, 1838-51.

Harbour Department, Admiralty. History of the Harbours of the United Kingdom, compiled by the Harbour Department of the Admiralty, Belfast. Folio. Plates. London, 1852.

DONORS. TITLE OF WORK.

Haywood, W. Report to the Committee, for general purposes, of the Commissioners of Sewers of the city of London, upon street cleansing, and in reference to the street-orderly system. By W. Haywood. Tract, 8vo. London, 1851.

———— Supplemental Report, addressed to the Commissioners of Sewers of the city of London, upon street cleansing, and in reference to the street-orderly system. By W. Haywood. Tract, 8vo. London, 1852.

———— Report of the works executed by the Honorable Commissioners of Sewers of the city of London, during the year 1851. By W. Haywood. Tract, 8vo. London, 1852.

Hogkinson, E. Experimental researches on the strength, and other properties of cast iron, with the development of new principles, calculations deduced from them; and inquiries applicable to rigid and tenacious bodies generally. By E. Hodgkinson. 8vo. Plates. London, 1852.

[Forming a second part to the fourth edition of Tredgold's practical essay, 'On the Strength of Cast Iron and other Metals.']

Holdsworth, A. H. Water bulk-heads, for reducing the temperature and arresting fire in Ships, or Vessels; with an appendix, containing extracts from reports made to the Board of Admiralty, and from evidence taken by a Committee appointed by that Board, to inquire into the claim of compensation, &c. By A. H. Holdsworth. Tract, 8vo. London, 1852.

Homersham, S. C. The Metropolis, and its Municipal Administration; showing the essentials of a sound system of municipal self-government, as applicable to all town populations, and the subject matters that come properly within the range of municipal administration. By J. Toulmin Smith. Tract, 8vo. London, 1852.

Hopkins, E. On the connection of Geology with Terrestrial Magnetism; showing, the general polarity of matter,

DONORS. TITLE OF WORK.

the meridional structure of the crystalline rocks, their transitions, movements, and dislocations, including the sedimentary rocks, the laws regulating the distribution of metalliferous formations, and other terrestrial phenomena. By E. Hopkins. 2nd edition. 8vo. Plates and Cuts. London, 1851.

Hübbe, Heinrich. Gutachtlichen Erörterungen der Ursachen der forts-chreitenden Vertiefrung der Elbeam Altonaer Hafen. By Heinrich Hübbe. Tract, folio. Hamburgh, 1851.

———————— Fortsetzung der gutachtlichen Erörterungen. By Heinrich Hübbe. Tract, folio. Hamburgh, 1851.

Institution of Civil Engineers of Ireland; Transactions of, Vols. II. and III. 8vo. Plates and Cuts. Dublin, 1848-49.

Institution of Mechanical Engineers; Reports of the Proceedings at the General Meetings, held at London on the 30th June, and at Birmingham on the 30th July, the 22nd October 1851, the 28th January, and the 28th April 1852. Tract, 8vo. Plates. London and Birmingham. 1851-52.

Johnson, W. Practical Mechanic's Journal. By W. Johnson. Vols. I., II., III., and IV. 4to. Plates and Cuts. London, 1848-52.

Jones, J. H. Annual Report of the Progress of Chemistry, and the allied sciences, physics, mineralogy, and geology; including the applications of chemistry to pharmacy, medicine, agriculture, the arts and manufactures. By J. Liebig and H. Kopp. Edited by A. W. Hofman and W. De la Rue. Vols. I. and II. 1847 and 1848. 8vo. London, 1849-50.

Kennedy, Major J. P. A Railway caution!! or exposition of changes required, in the law and practice of the British Empire, to enable the poorer districts to provide for themselves the benefits of railway intercourse, and to forewarn the government and the capitalists of British India, &c. Illustrated in

DONORS. TITLE OF WORK.

reports, addressed to the proprietors and directors of the Waterford and Limerick Railway Company. By Major J. P. Kennedy. Tract, 8vo. Calcutta, 1849.

Koninklijk Instituut van Ingenieurs. Uittreksels mit vreemde Tijdschriften voorde leden van het. Nos. IV. and V. 4to. Plates. 'sGravenhage, 1851.

Lacon, W. S. The loss of the Orion, the Amazon, and the Birkenhead. A letter to the Right Honourable the President of the Board of Trade, on the management of ships' boats. By W. S. Lacon. Tract, 8vo. Cuts. Second Edition. London, 1852.

Lalanne, Léon. Examen critique d'un tableau graphique publié par M. Davaine, pour la détermination des superficies de déblai et de remblai, et des largeurs des profils nécessaires à la reduction des projets, et nouvelles applications de la géométrie anamorphique. Par Léon Lalanne. Tract, 8vo. Plates. Paris, 1850.

[Extrait des Annales des Ponts et Chaussées.]

——————— Mémoire sur les tables graphiques et sur la géométrie anamorphique, appliquées à diverses questions qui se rattachent à l'art de l'ingénieur. Par Léon Lalanne. Tract, 8vo. Plates. Paris, 1846.

[Extrait des Annales des Ponts et Chaussées.]

——————— Rapport fait au nom du comité des arts mécaniques de la Société d'encouragement des arts et métiers, sur un abaque ou compteur universel. Par Léon Lalanne. By Théod. Olivier. Tract, 4to. Paris, 1846.

——————— Institut de France. Académie Royale des Sciences. Rapport sur un mémoire de M. Léon Lalanne, qui à pour objet la substitution de plans topographiques à des tables numeriques à double entrée. Par MM. Élie de Beaumont, Lamé et Cauchy. Tract, 4to. Paris. No date.

Literary and Philosophical Society of Manchester; Memoirs

DONORS.	TITLE OF WORK.
	of. Vols. I., II., and III., and vol. IX. 2nd Series. 8vo. Plates. Warrington, 1785-90.
Lindley, W.	Vereinbarung mit den interessenten der vereinigten drei Wasserkünste und Anlegung einer Wasser-Versorgungs-Anstat von Staatswegen. By W. Lindley and W. C. Mylne. 4to. Plate. No place or date.
————	Abrechnung über die auf den Hammerbrook verwendeten Ausgaben. By W. Lindley. 4to. No place or date.
————	Bericht, die Verbesserung des Hammerbrooks betreffend; nebst Grundriss. By W. Lindley. 4to. Plate. Hamburgh, 1840.
————	Bericht die Wasseransammlung im Hammerbrook in den Monaten Februar und Marz 1850 betreffend. By W. Lindley. 4to. Hamburgh, 1850.
————	Erlänterungen über die Anlage und den Zustand der Stadt-Wasserkunst. By W. Lindley. 4to. Plate. Hamburgh, 1846.
————	Fernere Maassreglu bei Vollendung der Anlage der Stadt Wasserkunst. By W. Lindley. 4to. No place or date.
————	Fernere Maasregelu in Bezugaufden Plan der Verbesserung des Hammerbrooks. By W. Lindley. 4to. Plate. No place or date.
————	Schlussbericht über die ausgeführten Anlagen zur Verbesserung des Hammerbrooks. By W. Lindley. 4to. Plate. Hamburgh, 1847.
————	Uebernahme der Neuen Elb-Wasserkunst u. w. d. a. By W. Lindley. 4to. No place or date.
————	Weitere Maassregelu in Bezugaufden Anlage der Stadt Wasserkunst. By W. Lindley. 4to. No place or date.
————	Weitere Maassregelu wegen der Stadt Wasserkunst. By W. Lindley. 4to. No place or date.

DONORS. TITLE OF WORK.

Lloyd, J. A. Papers relating to proposals for establishing colleges of art and manufactures, for the better instruction of the industrial classes. By J. A. Lloyd. Tract, 8vo. London, 1851.

Loseby, E. J. Improvements in Time-keepers. By E. J. Loseby. Tract, 8vo. London. No date.

Manby, Charles, (Secretary.) Amveisung zum Gembranche des englischen Rechenschiebers. By Dr. L. C. Schulz von Strassnitzki. Tract, 8vo. Plates and Cuts. Wien, 1843.

———— Handbuch der besondern und allgemeinen Arithmetik fur Praktiker, zunächst für das Selbststudium gemeinverständlich abgefasst. By Dr. L. C. Schulz von Strassnitzki. 8vo. Wien, 1848.

———— Handbuch der Geometrie für Praktiker gemeinverständlich zunächst für das Selbststudium abgefasst. By Dr. L. C. Schulz von Strassnitzki. 8vo. Cuts. Wien, 1850.

———— Professor Schulz von Strassnitzki's Rechenschieber. By Auton Schefczik. Tract, 8vo. Cuts. Wien, 1845.

———— Address, delivered at the anniversary meeting of the Geological Society of London, on the 20th February, 1852; prefaced by the announcement of the award of the Wollaston Palladium Medal, and the proceeds of the donation fund for the same year. By W. Hopkins. Tract, 8vo. London, 1852.

———— Geological Society of London. Annual General Meeting, Feb. 20, 1852. Report of the Council. Tract, 8vo. No place or date.

Marshall, J. G. B. On the theory of mechanics, as applied to works of construction. By J. G. B. Marshall. Tract, 4to. Cuts. London, 1852.

[Reprinted from the Civil Engineer and Architects' Journal.]

Maus, Chevalier H. Rapport sur les études du chemin de fer, de Chambéry à Turin, et de la machine proposée, pour exécuter le tunnel des Alpes, entre Modane et

DONORS. TITLE OF WORK.

Bardonnêche, par M. le Chevalier H. Maus, et Rapport rédigé au nom de la commission, chargée de l'examen des ces études, par M. le Chevalier Pierre Paleocapa, suivi des procès verbaux des séances, de cette commission. Folio. Plates. Turin, 1850.

Miller, J. F. Synopsis of meteorological observations, made at Whitehaven, Cumberland, in the year 1850. By J. F. Miller. Tract, 8vo. Edinburgh, 1851.

[Excerpt Edinburgh New Philosophical Journal, for October, 1851.]

——— Synopsis of the fall of rain in the English lake and mountain district, &c., in the year 1851. By J. F. Miller. Tract, 8vo. Whitehaven, 1852.

——— On the meteorology of the lake district of Cumberland and Westmoreland; including the results of experiments on the fall of rain, at various heights, up to 3166 feet above the sea-level. By J. F. Miller. Tract, 4to. Cuts. London, 1851.

[Excerpt Philosophical Transactions, for 1851.]

Moseley, Rev. H. On the rolling motion of a cylinder. By the Rev. H. Moseley. Tract, 4to. Cuts. London, 1851.

[Excerpt Philosophical Transactions, part ii., 1851.]

Murray, J. Description of a project, with plans and sections, submitted to the Metropolitan Commissioners of Sewers, for the drainage and sewerage of London, in pursuance of their advertisement of July, 1849, with an appendix containing additional notes. By J. Murray. Tract, folio. Plates. London, 1852.

——— Proposed improvement of the estuary of the river Tees. By J. Murray. Tract, folio. Plate. London, 1852.

Museum of Practical Geology. Inaugural discourse at the opening of the Government School of Mines and of Science applied to the Arts; 6th November, 1851. [illegible] Henry de la Beche. Tract, 8vo. London,

DONORS. TITLE OF WORK.

Museum of Practical Geology. On the national importance of studying abstract science, with a view to the healthy progress of industry. By Dr. Lyon Playfair. Tract, 8vo. London, 1851.

[Being an introductory lecture, to the course of Chemistry. Session 1851-52.]

———————————— On the relations of natural history to geology and the arts. By E. Forbes. Tract, 8vo. London, 1851.

[Being the introductory lecture to the course to be delivered, during the Session 1851-52.]

———————————— On the importance of cultivating habits of observation. By R. Hunt. Tract, 8vo. London, 1851.

[Being the introductory lecture to the course on Mechanical Science. Session 1851-52.]

———————————— On the importance of special scientific knowledge, to the practical metallurgist. By J. Percy, M.D. Tract, 8vo. London, 1852.

———————————— On the science of geology, and its applications. By A. C. Ramsay. Tract, 8vo. London, 1852.

———————————— On the value of an extended knowledge of mineralogy and the processes of mining. By Warington W. Smyth. Tract, 8vo. London, 1852.

[Being the introductory lecture to the course on Mineralogy. Session 1851–52.]

Newlands, J. Reports to the Health Committee, of the borough of Liverpool, by the Borough Engineer, Inspector of Nuisances and Medical Officer of Health. By J. Newlands, T. Fresh and W. H. Duncan. 8vo. Liverpool, 1851.

Northumberland, Duke of. Report of the Committee, appointed to examine the Life-Boat models, submitted to compete for the Premium offered by His Grace, the Duke of Northumberland, to which is added, a list of the existing life-boat, rocket, and mortar stations, and an abstract of the wrecks, which occurred on the

DONORS. TITLE OF WORK.

shores of the British Isles in 1850, with Appendix. Folio. Plates and Cuts. London, 1851.

Parkes, J. Agricultural Drainage. By J. Parkes. Tract, 8vo. Cuts. London, 1850.

——— Essays on the philosophy and art of land drainage. By J. Parkes. Tract, 8vo. London, 1848.

——— Fallacies of Land drainage exposed. By J. Parkes. Tract, 8vo. London, 1851.

Penrose, F. C. An investigation of the principles of Athenian Architecture, or the results of a recent survey, conducted chiefly with reference to the optical refinements, exhibited in the construction of the ancient buildings at Athens. By F. C. Penrose. Folio. Plates and Cuts. London, 1851.

[Published by the Society of Dilettanti.]

Phillips, J. Metropolitan Commission of Sewers. General particulars and descriptions, for the information of parties, desirous of tendering for the execution of the several kinds of works, required to be done, in constructing, rebuilding, altering, and cleansing the sewers, drains, &c., &c. Tract, 8vo. London, 1852.

Pole, W. Gas works and gas lighting in London. By W. Pole. Tract, 8vo. London, 1852.

[Excerpt Weale's London and its vicinity. Exhibited in 1851.]

——— Diagrams illustrating the action of the forces on the crank of a steam engine. By W. Pole. Tract, 8vo. Plates. London, 1852.

[Reprinted from Newton's London Journal of Arts.]

——— A familiar essay on the errors of time-keepers. By W. Pole. Tract, 8vo. Bombay, 1846.

——— On the comparative loss by friction, in beam and direct action steam engines. By W. Pole. Tract, 4to. London, 1844.

[Read at a Meeting of the Inst. C.E., Feb. 7, 1843.]

——— Water Supply of London. By W. Pole. Tract, 8vo. London. No date.

[Excerpt Weale's London and its vicinity. Exhibited in 1851.]

DONORS. TITLE OF WORK.

Pole, W. On the pressure and density of steam; with a proposed new formula for the relation between them, applicable particularly to engines working with high-pressure steam expansively. By W. Pole. Tract, 8vo. London, 1849.
[Excerpt Minutes of Proceedings, Inst. C. E., Vol. VI., 1847.]

——— On the strength and deflection of beams. With applications to the Britannia and Conway tubular bridges. By W. Pole. Tract, 4to. Plates and Cuts. London, 1850.
[Excerpt Clark's Treatise on "The Britannia and Conway Tubular Bridges."]

——— Musical Instruments in the Great Exhibition of 1851. By W. Pole. 8vo. London, 1850.
[Reprinted, with additions, from Newton's London Journal of Arts, for private circulation.]

Poole, B. Statistics of British Commerce; being a compendium of the productions, manufactures, imports and exports of the United Kingdom, in agriculture, minerals, merchandize, &c. By B. Poole. 8vo. London, 1852.

Pratt, J. T. Suggestions to the promoters and members of Friendly Societies. By J. T. Pratt. Tract, 8vo. London, 1852.

Queen's University in Ireland. Calendar of Queen's College, Cork. 8vo. Plate. Dublin, 1851.

Radford, W. The collected works of Sir Humphry Davy, Bart., LL.D. F.R.S. By J. Davy, M.D. 9 volumes, 8vo. Plates. London, 1839-40.

——— A glossary of terms used in Grecian, Roman, Italian, and Gothic Architecture. 3 vols. 8vo. 5th Edition. Plates and Cuts. Oxford, 1850.

——— The theory, practice, and architecture of bridges of stone, iron, timber, and wire, with examples on the principle of suspension, 3 volumes, 8vo. Plates and Cuts. London, 1843.

——— Supplement to ditto. By G. R. Burnell. Parts 1, 2, and 3. 8vo. Plates. London, 1850.

DONORS. TITLE OF WORK.

Radford, W. Principes d'hydraulique et de pyrodynamique. Par M. Dubuat. 3 vols., 8vo. Nouvelle Edition. Paris, 1816.

Randell and Saunders, Messrs. Price List of Bath stone, delivered to all the principal towns and cities in the kingdom; with a description of their patent brick, tile, and pipe machine, and patent drainage bricks. Tract, 8vo. Map and Cuts. Bath, 1851.

Rankine, W. J. M. On the velocity of sound in liquid and solid bodies, of limited dimensions, especially along prismatic masses of liquor. By W. J. M. Rankine. Tract, 8vo. No place or date.

[Excerpt the Cambridge and Dublin Mathematical Journal, November, 1851.]

——— ——— Supplementary papers, on the mechanical action of Heat, especially in gases and vapours. By W. J. M. Rankine. Tract, 4to. Plate. Edinburgh, 1851.

[Excerpt Transactions of the Royal Society of Edinburgh. Vol. XX., Part 2.]

——— ——— On the means of improving the water supply of Glasgow. Two Letters. By W. J. M. Rankine and J. Thomson. Tracts, 8vo. Glasgow, 1852.

Rendel, J. M. Report of Robert Stephenson, C.E., and Francis Beaufort, hydrographer to the Admiralty, on the Docks at Birkenhead, 1851. With the evidence referred to in the Report. Tract, folio. London, 1851.

Rennie, Sir J. The theory, formation, and construction of British and Foreign Harbours. By Sir J. Rennie. Parts 8 to 15. Folio. Plates. London, 1851-52.

Ritchie, R. On the ventilating and warming of buildings, and heating of baths, as practised by the ancients. By R. Ritchie. Tract, 8vo. Plates. Edinburgh, 1851.

[Excerpt Transactions of the Architectural Institute of Scotland, Session 1850-51.

DONORS. TITLE OF WORK.

Ritchie, R. On the use of Metals, especially of copper and iron by the ancients. By R. Ritchie. Tract, 8vo. Edinburgh, 1852.

[Excerpt Transactions of the Architectural Institute of Scotland, Session 1851-52.]

Roberts, H. The model houses for families, built in connexion with the Great Exhibition of 1851, by command of H.R.H. Prince Albert. By H. Roberts. 8vo. Plates and Cuts. London, 1851.

Robinson, Rev. Dr. Description of an improved Anemometer, for registering the direction of the wind, and the space which it traverses in given intervals of time. By the Rev. Dr. Robinson. Tract, 4to. Plate. Dublin, 1851.

[Excerpt Transactions of Royal Irish Academy, Vol. XXII.]

Royal Agricultural Society of England; Journal of. Vol. XII. Parts 1 and 2. Plates and Cuts. London, 1851.

Royal Astronomical Society; Memoirs of. Vols. XIX. and XX. 4to. London, 1851.

—————————— Monthly Notices of,—containing papers, abstracts of the papers, and reports of the proceedings of the Society. Vols. I. to VII. and Vols. X. and XI. 8vo. Plates and Cuts. London, 1827-50-51.

Royal Engineers. Papers connected with the duties of the corps, and papers on Military subjects, compiled from contributions of the Officers. Vols. VII. to X., and Vols. I. and II. New Series. 4to. Plates and Cuts. London, 1845-52.

Royal Institute of British Architects. Address of the,—explanatory of their views and objects, and the regulations adopted at a meeting, held July 2nd, 1834; with a list of the Members. Tract, 8vo. London, 1835.

—————————— List of the Members, and Report of the Council, read at the Annual General Meeting held 5th May, 1851, with the balance-sheet, and list of contributors to the collection and library. Tract, 4to. London, 1851.

DONORS. TITLE OF WORK.

Royal Institute of British Architects. List of the Members, Reports of the Council read at the Annual General Meetings held in May 1839-50, with the balance-sheets, and list of contributors to the collection, library, and general funds. Tract, 4to. London, 1839-50.

Royal Geographical Society of London; Journal of, Vol. XXI. 8vo. Plates and Cuts. London, 1851.

Royal Irish Academy; Proceedings of,—for the year 1850-51. Volume V., Part 1. Cuts. Dublin, 1851.

Royal Scottish Society of Arts; Transactions of,—Vols. I., to III. 8vo. Plates and Cuts. Edinburgh, 1839-51.

Royal Society of London; Proceedings of,—Vol. VI., Nos. 79 to 85. 8vo. London, 1851-52.

Royal Society of Edinburgh; Transactions of,—Vol. XX., Part 2. 4to. Plates. Edinburgh, 1851.

——————— Proceedings of,—Vols. II. and III., Nos. 2 to 41, inclusive, with Title Page, Table of Contents and Index to Vol. I. 8vo. Edinburgh, 1832-50-51.

——————— Laws of,—January 18, 1836. Tract, 4to. Edinburgh, 1851.

Shrapnel, Captain. Stradametrical survey of London and its environs. Part II., containing upwards of fourteen millions, eight hundred thousand mean distances, with their relative distances, to or from every street, square, or place in London. By Captain Shrapnel. 12mo. London, 1852.

Sidney, S. Rides on railways, leading to the Lakes and mountain districts of Cumberland, North Wales, and the dales of Derbyshire; with a glance at Oxford, Birmingham, Liverpool, Manchester, and other manufacturing towns. By S. Sidney. 8vo. Plates and Map. London, 1851.

Smith, C. R. Remarks on Anglo-Saxon and Frankish remains. By C. R. Smith. Tract, 8vo. Plates. London, 1852.

[Excerpt Vol. II., "Collectanea Antiqua."]

DONORS. TITLE OF WORK.

Smithsonian Institution. Smithsonian Contributions to Knowledge. Vol. II. 4to. Plates and Cuts. Washington, 1851.

——————— Appendix I. to Vol. III. of the Smithsonian Contributions to Knowledge, containing an ephemeris of the planet Neptune for the year 1852. By Sears C. Walker. Tract, 4to. Washington, 1851.

——————— Fourth Annual Report of the Board of Regents, to the Senate and House of Representatives, showing the operations, expenditures, and condition of the Institution during the year 1849. Tract, 8vo. Washington, 1850.

——————— Smithsonian Reports. Notices of Public Libraries in the United States of America. By C. C. Jewett. Tract, 8vo. Washington, 1851.

Société des Ingenieurs Civils. Mémoires et comptes-rendus des travaux. Nos. 2 to 8. 8vo. Plates. Paris, 1848-50.

——————— Compte-rendu des séances, de Fevrier à Aôut, 1851. 8vo. Paris, 1851.

Statistical Society of London, Journal of,—Vol. XIV., Parts 3 and 4, and Vol. XV., Part 1. London, 1851.

Stephenson, R. M. A Geological Report on the Damoodah Valley. By D. H. Williams. Tract, 8vo. Plate. London, 1850.

Stevenson, T. Account of experiments upon the force of the waves of the Atlantic and German Oceans. By T. Stevenson. Tract, 4to. Plate. Edinburgh, 1845.

[Excerpt Transactions of the Royal Society of Edinburgh, Vol XVI.]

——————— Account of the holophotal system of illuminating lighthouses; being a description of the light of maximum intensity. With an appendix. By T. Stevenson. Tract, 8vo. Plates and Cuts. Edinburgh, 1851.

[Excerpt Transactions of the Royal Scottish Society of Arts.]

DONORS. TITLE OF WORK.

Stratford, Lieut. W. S., R.N. The Nautical Almanac, and astronomical ephemeris for the years 1834 to 1854. With appendices and supplements. 8vo. Cuts. London, 1834-51.

Thom, A. Statistics of Ireland, 1852. By A. Thom. Tract, 8vo. Dublin, 1852.
[Excerpt Irish Almanac Official Directory, 1852.]

Turner, T. The law of patents, and registration of invention and design in manufacture, with statutes, forms and rules. By T. Turner. 8vo. London, 1851.

Twining, T., Junr. Notes on the organization of an industrial college for artizans. By T. Twining, Junr. Tract, 8vo. London, 1851.
[For private circulation.]

University College, London. Proceedings at the Annual general meeting of the members of the college, 25th February, 1852: Report of Council and Financial Statements. Tract, 8vo. London, 1852.

Vetch, Captain, R.E. A short description of the plans of Captain James Vetch, R.E., for the sewerage of the metropolis. By L. D. B. Gordon. Folio. Maps. London, 1851.

Weale, J. A Treatise on the Cornish pumping engine. Part III. Analytical investigation of the action of the engine. By W. Pole. 4to. Plate. London, 1848.

White, W. Papers on railway and electric communications, arctic and antarctic explorations, and the sanitary movement. By W. White. 8vo. Edinburgh, 1850-51.

White, D. B., M.D. Some observations on the patent water ballast, pumps and stowage bags. By D. B. White, M.D. Tract, 8vo. Plate. Gateshead, 1851.

Wicksteed, T. Observations upon the nature, properties and value of the patent solid sewage manure, with a description of Wicksteed's patent process for its manufacture, and a statement, showing the origin of the scheme for removing the sewerage of the metro-

DONORS. TITLE OF WORK.

polis and other towns by means of a tunnel sewer, having an artificial fall. By T. Wicksteed. Tract, 8vo. London, 1851.

Wilson, W. A proposal for a new cattle-market, for the supply of London, to be erected on the north bank, of the Thames, near Blackwall. By W. Wilson. Tract, 8vo. Plates. London, 1851.

Woolrych, E. H. Metropolitan Sewers. Concise Statement of the main features, and of the plans, for the Drainage of the Metropolis, sent in pursuance of the Resolution of the Court, 20th August, 1849. 1st and 2nd Series. Folio. Cuts. London, no date.

——— Report on ditto; presented to the Court of Sewers, held on the 15th March, 1850. Folio. London, no date.

Wyatt, M. D. The Construction of the Building for the Exhibition of the Works of Industry of All Nations, 1851. By M. D. Wyatt. Tract, 4to. Cuts, London, 1851.

[Excerpt the Official Illustrated Catalogue.]

——— An attempt to define the principles which should determine form in the decorative arts. By M. D. Wyatt. Tract, 8vo. London, 1852.

[Read before the Society of Arts, April 21, 1852.]

MISCELLANEOUS.

Jones, J. E. Bust of the late Right Honourable Sir Robert Peel, Bart., M.P.

Pellatt, Apsley. Bust of Apsley Pellatt, Esq., M.P.

PRINTS AND ENGRAVINGS.

Hoggar, R. S. Plan of the city of Oxford, from actual survey. By R. S. Hoggar. Oxford, 1850.

[Mounted and folded in 8vo case.]

Lane, C. B. Two Lithographic Drawings showing the arrangements of the Chemical Laboratory of Queen's College, Cork.

DONORS. TITLE OF WORK.

Mylne, R. W. Section of the well sunk at the Bank of England.

Pupils and Assistants of the President. Portrait (framed) of J. M. Rendel (President).

Rickman, W. Portrait of the late G. B. Maule, Assoc. Inst. C. E.

Shelley and Treppass, Messrs. The Trihedral view of the Palace for the Exhibition of the Industrial products of Mankind.

Simpson, J. Copies of six Drawings of engine, boiler, pumps, pipes, reservoirs, &c., for the York Water Works, 1781 to 1785. By J. Smeaton, Civil Engineer.

MAPS.

Meikleham, E. Map of the country for ten miles round Glasgow. By E. Meikleham.

Mylne, R. W. Topographical Map of London, and its environs: coloured geologically. By R. W. Mylne.

OFFICERS.—1853.

COUNCIL.

PRESIDENT.

JAMES M. RENDEL, F.R.S.

VICE-PRESIDENTS.

ISAMBARD K. BRUNEL, F.R.S.
JOSEPH LOCKE, M.P., F.R.S.
JAMES SIMPSON, F.G.S.
ROBERT STEPHENSON, M.P., F.R.S.

MEMBERS.

GEORGE P. BIDDER.
JOSEPH CUBITT.
JOHN E. ERRINGTON.
JOHN FOWLER.
CHARLES H. GREGORY.
JOHN HAWKSHAW.
JOHN R. M'CLEAN.
CHARLES MAY.
JOHN PENN.
JOHN SCOTT RUSSELL, F.R.S.

ASSOCIATES.

JOHN GEORGE APPOLD.
EDWARD LADD BETTS.

AUDITORS.

JOHN GEORGE APPOLD.
WILLIAM POLE.

TREASURER.

EDWARD MARJORIBANKS.

SECRETARY.

CHARLES MANBY, F.R.S.

HONORARY COUNCILLORS.

PAST PRESIDENTS.

JAMES WALKER, F.R.S., L. & E.
JOSHUA FIELD, F.R.S.
SIR JOHN RENNIE, F.R.S.
SIR WILLIAM CUBITT, F.R.S.

HONORARY COUNSEL.

CHARLES F. F. WORDSWORTH.

HONORARY SOLICITOR.

WILLIAM TOOKE, F.R.S.

HONORARY ARCHITECT.

THOMAS HENRY WYATT, F.R.I.B.A.

January 11th, 1853.

JAMES MEADOWS RENDEL, President, in the Chair,

The following candidates were balloted for, and duly elected:— Stephen Collins Court, as a Member;—Edward Bagot, John Hodgson, and Arthur Sinclair, as Associates.

No. 881.—"On the Nature and Properties of Timber, with descriptive particulars of several methods, now in use, for its Preservation from Decay." By Henry Potter Burt, Assoc. Inst. C.E.[1]

Timber, by which is understood all the descriptions of wood, both of foreign and home growth, which are used for engineering, shipbuilding and architectural purposes, is an article of such immense importance, and enters so largely into works of all kinds, that an essay upon its history, peculiarities, uses, and preservation, can scarcely fail to be an interesting subject of inquiry, and the Author, whilst endeavouring to explain the views and observations, deduced from many years' experience, may reasonably hope, that, however imperfect, his efforts may be useful, in exciting a discussion worthy of the Institution, and in eliciting facts and details which will prove beneficial to the profession.

An inquiry into the history, cultivation, physiology, and properties, of timber, is of more than ordinary interest, not only on account of its almost unlimited application in construction, but in a commercial point of view, and it is likewise of great national importance, as having been the subject of fiscal regulations which, at one period, produced a large addition to the revenues of the kingdom; it is thus of sufficient importance to claim the attention of the political economist, the capitalist, and the consumer, as well as that of the civil engineer.

---

[1] The discussion upon this paper extended over portions of three evenings, but an abstract of the whole is given consecutively.

The peculiarities of timber, and its value for general purposes, embrace so wide a field for inquiry and observation, that it would be impossible, in the limits of this paper, to do more, than enter briefly, into the more important and useful bearings of the question,—sketching, as it were, a skeleton diagram of the subject, which others, having leisure and opportunity, may hereafter render complete.[1]

Historically, timber seems to have been naturally the earliest material known for construction—and shipbuilding one of its first recorded applications, for under Divine instruction, Noah "made himself an ark of gopher wood," (Gen. chap. vi. ver. 14.); and throughout the sacred volume, innumerable other instances occur of the use of timber, for the purposes of the artificer, in every branch of construction, whilst the Egyptian mummy cases and the utensils discovered at Nineveh, show that the early artisans must not only have been acquainted with mechanical contrivances, but must, also, have well understood the selection of those sorts of wood, which were of the most enduring character, and the least susceptible of decay.

In the ecclesiastical and castellated ruins of our own country, there are many existing proofs of the early use of timber; and some of the most interesting relics of antiquity, such as King Arthur's round table at Winchester, the coronation chair, and the doors of the inner chapel at Westminster Abbey, and many other specimens of great interest still existing in many parts of the kingdom, not only exhibit considerable skill in the artificer, but testify that the timber of our own island, yields to none in point of strength, and enduring qualities.

Chemically considered, the ultimate elements of wood consist of carbon, oxygen, and hydrogen, but it may more proximately be described as a compound of woody fibre, starch, gum, sugar, and vegetable acids,—these form the constituents of all the organs of a tree and are essential to its existence, and it would appear that on the varying proportions of these constituents, many of the peculiarities and much of the strength and durability of timber must depend.

---

[1] This subject is extremely well treated in the article "Wood," partly abridged from papers by Professor Forbes, and published in "Tomlinson's Cyclopædia of Useful Arts."—Editor.

Chemical transformation, or in other words—decomposition, putrefaction, and decay, must form an essential part of this inquiry; and the nature, action, and results of these changes shall be briefly examined.

Woody fibres and all organic compounds, when in contact with other bodies, are liable to certain changes tending towards decomposition. There are two distinct modes in which these changes take place;—the first is, when the decomposition is effected by the agency of a body, which unites with one, or more of the constituents of the compound, and by this union causes the remaining elements to enter into a new form. In the second mode, the chemical affinity of the acting body causes the component parts of that acted on to combine with it.

A body, in the act of decomposition, exercises an influence upon any other body, with which it may be in contact, in the same manner that a body in the act of combustion inflames another combustible body, in its vicinity. In organic nature, besides those processes of decomposition, termed fermentation and putrefaction, another and not less striking class of change occurs in bodies exposed to the influence of the air; this is the act of gradual combination of their combustible elements—with the oxygen of the air—a slow combustion, or oxidation, to which the term eremacausis is usually applied,—the conversion of wood into humus is one of the numerous processes of this nature,—vegetable juices of any kind, moist sawdust, &c., cannot be exposed to the air, without immediately suffering a progressive change of colour and properties, during which oxygen is absorbed; these changes do not take place when water is excluded, or when the substances are kept at a low temperature, and it has been observed, that different woods require different degrees of heat, to affect the absorption of oxygen and consequently their eremacausis; the tendency to undergo this change is possessed in the highest degree by those substances which contain most nitrogen. The conditions which determine the commencement of decay, are of various kinds;—most woods, however, more, or less, oxidize slowly in the air, when simply moistened with water; in others, decay is retarded, or completely arrested, by all those substances which prevent fermentation, or putrefaction. Mineral acids, salts of mercury, aromatic substances, empyreumatic oils, and oil of turpentine,

possess similar action in this respect, and upon this principle, many preservative processes have been formed, which will be briefly explained under the head of the preservation of timber.

Dry-rot, the most formidable kind of decay to which timber is subject, occurs most frequently in ships, and in ill-ventilated houses; it renders the wood brittle, and so completely destroys the cohesion of its fibre, that it can be pulverized with the fingers. This disease has been considered dependant upon the growth of fungi, whose minute filamental spawn, separates the woody fibre, and by introducing moisture, which causes fermentation, the decomposition of the ligneous tissue immediately supervenes. It is, however, more probable, that it results, in many cases, from the timber having been felled at an improper season; either too soon in the autumn, before the sap has perfectly returned to a dormant state, after its active circulation during the growing season, or else so late in the spring, that active vegetation has commenced and the tree is, consequently, partially filled with those juices, which afterwards hasten its decay. It will have been observed, that trees frequently exhibit symptoms of active vegetation, and even throw out foliage, during the first, and sometimes in the second year, after they have been felled; this tenacity of life causes the acids,• of which the sap is composed, to combine with the oxygen of the air and to produce an active fermentation, which induces the species of disease termed "dry-rot."

The natural history of timber, its growth, age, organic structure, and the peculiarities of formation, upon which depend its strength, durability and adaptation for particular purposes, embrace so wide a field of inquiry, that they cannot be entered upon here; all that can be done is to insert a few remarks on such points as have more immediate reference to the practical use of timber for engineering purposes.

English Oak is a dense compact wood, of exceedingly slow growth; at mature age and when of good sound quality the heart weighs 60 lbs. per cubic foot.

The probable age at which good oak timber is generally brought to market, is from eighty to one hundred years. Oak at half this age is generally in active growth and consequently contains too much sap for the better purposes, to which it is applicable. Innumerable instances might be cited of the great

age, and enormous size to which oak has attained, in this country, such as the famous Golyens oak, felled in Monmouthshire in 1810. This magnificent tree had, it was recorded, been improving for four hundred years, and with the exception of a portion at the intersection of its principal limbs, was perfectly sound, when it was cut down; it contained 2,426 cubic feet of timber, and was sold for £500; this tree had never been pruned, and was not more than 10 feet high in the stem before the lateral branches commenced.

The proper period for felling oak is in the winter season, when the sap is in a dormant state; if cut during active vegetation, the timber is generally considered more susceptible of dry-rot; the reason of this seems to be, that the sap and the juices by which the tree is matured, are highly charged with putrefactive matter, and consequently aid the predisposition to decay.

A piece of English oak, experimented on by the Author, weighed 57½ lbs. per foot cube; after being dried for twelve hours, at a temperature of 90°, it lost 2½ lbs., and after six hours' slow boiling it absorbed 2 lbs. of water; after immersion for six hours in creosote, at a temperature of 129°, under a pressure of 150 lbs. per square inch, it absorbed 2 lbs. of creosote, per foot cube.

English Elm, is a timber of great utility, and of considerable strength and durability, it is little inferior, in specific gravity, to oak, possesses great toughness, and is of great value for the agricultural carpenter, for the carriage builder, for foundations under water, and for many engineering purposes; it was, in former times, extensively used for water-pipes, and pumps, but for this purpose it has long been superseded by metal.

Elm timber used in buildings, is more liable than other sorts of wood to be attacked by worms;—in the removal of old farmhouses, where the wood, was to all appearance sound, it has been found, when violently shaken, or on being struck with a hammer, to crumble into dry powder. Its general liability to decay may be attributed, in a great degree, to the length of time required for seasoning it, which renders this operation almost impracticable.

A specimen of elm weighed 56 lbs. per foot cube, when cut out; after being dried for twelve hours, at a temperature of

90°, it lost 15 ozs., and absorbed, after six hours' slow boiling, 13 ozs. of water; after six hours' pressure at 150 lbs. to the inch and at a temperature of 129° it absorbed 10 lbs. of creosote, per foot cube.

Beech is chiefly grown in plantations; it thrives best on calcareous soils, grows to great height and dimensions, and is principally used for common cabinet-makers' work; whilst very large quantities of the smaller wood are converted into charcoal. It is of rapid growth; hence its small specific gravity, which is about 48 lbs. per cube foot, its porosity, and great susceptibility of decay; a specimen after twelve hours' drying at 90°, only lost 6 ozs., whilst after six hours' slow boiling, it absorbed 36 ozs. of water; a similar piece having been previously dried, after six hours' pressure at 150 lbs. per square inch at a temperature of 129° took up 48 ozs. of creosote, per cube foot. Beech is frequently used, in a green state, for foundations, and for piles for sea-walls, docks, &c., but it sometimes proves not to be of sufficient durability for such purposes, unless it be always submerged, or protected from atmospheric changes.

English, or Scotch Fir and Larch are of the same class and family, but of different value and utility. The weight of fir is 31 lbs., and of larch 36 lbs., per foot cube. Larch is the only kind of fir, grown in this country, possessing any great degree of durability, and its character, even in this respect, is much over-rated, as it greatly depends on the nature of the soil on which it grows, the purpose for which it is used, the nature of earth in which it is embedded, and many other circumstances of a local nature. Fir, from its rapid growth, is always abundant and cheap, and hence its use for so many common purposes. Previous to the use of fir and larch for railway sleepers and for fences, they were hardly known and little valued, now however their application has extended and their commercial value has increased; but even the best timber of this class can only be considered as fitted for temporary purposes, unless some artificial means be adopted for its preservation.

There are many other sorts of English timber of useful character—such as Ash, Birch, Walnut, Chestnut, Lime, Yew,

Sycamore, Hornbeam and others, which it will suffice only to name, before passing on to the subject of foreign timber.

The Parliamentary returns of the imports of foreign timber, exhibit the enormous extent of this branch of the commerce of this country; they show, that in 1849, the importation of timber, exceeded 1,733,617 loads, or 86,680,850 cubic feet, exclusive of mahogany and other woods for ornamental purposes, and that quantity, though slightly below the average of some former years, may be taken as the average annual supply, received by Great Britain from foreign countries.

The introduction of railways has increased the demand for foreign timber, and there seems every probability, that the same supply will be required for many years to come.

The foreign timbers principally imported are—

Memel, Dantzic and spruce Firs, red and yellow Pine, American Oak and rock Elm, and Indian Teak.

By the term Memel, is understood the best description of Baltic wood; it is a species of fir, growing particularly straight, and of very great uniformity in size, the average being 30 feet in length and 13 inches square; the age of this kind of timber, as brought to market, is generally considered to be fifty years; the larger and longer sizes being proportionably older. It is chiefly brought from the islands of the Baltic, from Norway, and from Sweden; it is cut in the fall of the year, and during the winter season, then hewn, or sawn die square, and floated down the rapids, in the flood seasons, to the ports of delivery; usually leaving the ports as soon as the breaking up of the ice enables the ships to pass down the rivers, and the cargoes begin to arrive in England in June and continue through the summer.

Memel timber is considered the most durable of its kind, probably from its being more resinous, and containing a greater quantity of turpentine, and from more care being taken in the selection of sound and heavy timber; the same causes also account for its lesser susceptibility to dry rot; nevertheless, like all other kinds of soft wood, if placed in situations inaccessible to atmospheric air, or subject to frequent variations of temperature, or humidity, it decays rapidly; and when once disease commences, it can scarcely ever be eradicated. A

specimen of Memel deal weighed 38 lbs. per foot cube; in drying, at a temperature of 90° it lost 10 ozs.; in six hours' boiling, it absorbed 2 lbs. of water; and a corresponding piece, after six hours' pressure at 150 lbs. per inch, absorbed 8 lbs. per foot, of creosote, at a temperature of 120°.

Yellow pine, is extensively used; its specific gravity is somewhat less than Memel, but its strength is nearly the same; generally speaking, perhaps, not quite so great. A specimen weighed 34 lbs. per foot cube, absorbed 2½ lbs. of water in six hours' boiling, and a similar piece absorbed 8½ lbs. of creosote, under the same circumstances as before.

It must be obvious, that the softer and more porous the texture of timber, the more susceptible it is of imbibing humidity, and the more liable it, consequently, is to decay; but from the same causes, soft, light, and porous woods are peculiarly adapted for undergoing the process of saturating with preservative fluids, which they imbibe more freely and in larger quantity, than the harder and heavier kinds of timber.

The timber of tropical climates, in consequence of the introduction of railways in India, is at the present time, occupying much attention, and forms a subject of deep anxiety, to those who are interested in these great works. Looking at the enormous extent of the Indian Empire, it may seem surprising that it should be necessary, in the construction of the railway works now in progress, to send the greater part of the timber from England; yet such is the fact, and it does appear almost incredible, that although there is no timber to spare of native British growth, yet that it can be purchased from other countries, imported to this country, converted to its required dimensions, submitted to various chemical processes for its preservation, and finally delivered in India, at a cheaper rate than sleepers would cost, made from the indigenous woods of the country. This however arises from several causes; the chief of which is, that nearly all the good timber, grown in tropical climates, is so hard, as to be exceedingly difficult of conversion; it cannot be sawn, and can only be reduced to rough sizes by hewing; and secondly—that good timber is only found, in large quantities, in the interior of the country, where there are neither roads, nor canals, and the cost of land carriage by bullock carts, is so great, as to amount to a prohibition of its

use. It is true, that some woods of soft, light kinds are found, but they are so soon devoured by the white ants, that they are never used for permanent purposes, and the difficulty and danger of conveying creosote to India by ships, prohibit the idea of attempting the introduction of the preserving process. Good timber will, however, most probably be found, and is only one amongst the innumerable treasures of that great country, which will be opened up for the uses of everyday life and the advantage of mankind, when the railroads now in course of construction in these almost trackless and inaccessible countries, are brought into operation.

One of the most valuable woods of tropical countries is Teak, which grows to an enormous size, is particularly straight and free from knots, and has the peculiar property of resisting the attacks of the insects; it possesses greater toughness than almost any other wood of similar density, and is less liable to dry-rot, or other disease. Some of these valuable properties of teak, seem to arise from its juices, or sap, containing oleaginous matter, a peculiarity common to many of the harder woods: African Teak, Rosewood, the white Oak, and other varieties of African timber, all possess, in a greater, or lesser degree, this quality, and it is to this cause that may be traced their great durability. Both the African and Indian Teak are extensively used for ship-building, and are found particularly useful for the framework of railway carriages and for the better kinds of furniture.

American Oak and rock Elm, are but little known in this country, and have only been introduced, in any considerable quantity, within the last few years. The former is generally used by cabinet-makers and carriage-builders, principally in consequence of its great size, uniform texture, straightness of grain, and little tendency to warp. Its specific gravity is somewhat less than English oak, but it seems to be a valuable acquisition to manufacturers. Rock elm is also but little known in this country, although it promises to become extensively used for engineering purposes. It is beautifully uniform in texture and growth, perfectly straight and free from knots; its specific gravity is equal to that of oak, whilst its great length and uniform size render it particularly useful for longitudinal ties, piles, and other purposes which require great length, combined with uniformity in dimension. A baulk

54 feet long—tapered only 1¼ inch—and when slabbed, was 12¼ inches square in section and 51½ feet long. A specimen cut from this baulk weighed 50 lbs. per foot cube; it absorbed 8 ozs. of water in boiling for six hours; and imbibed 6 ozs. of creosote, under the conditions before named.

In the commencement of this paper, allusion was made to some of the diseases of timber, and the causes which lead to its premature decay, it is now proposed to describe the several means which have been devised and adopted for its preservation.

Bituminous substances appear, at a very early period, to have been used as means of preservation. Noah was commanded to pitch the ark within and without, and accounts of the use of similar agents are found in other passages of ancient history. The Egyptians, who had made rapid advances in the arts and sciences, paid great attention to the preservation of their dead, and embalming and other means were adopted for this purpose; the most desirable kinds of wood were selected as receptacles for the bodies, and bituminous substances were used to increase their durability; the researches of antiquarians and travellers show, that although thousands of years have elapsed, since these experiments were made, they almost defy comparison with all the present agents known as effective antidotes, against the ravages of time, or the causes of decay. It is singular, however, that one of the substances now most used for preserving timber, should bear a close analogy, in its nature and composition, to those which appear to have been the earliest known.

In modern times, the rapid decomposition of timber and its predisposition to decay, have seriously engaged the attention of naturalists, chemists and scientific men, and many remedies have been proposed, some of which, however, were originally directed, rather to the preservation of animal, than vegetable substances, and were tried in the latter cases, only in consequence of their being successful in the former. The first patent, on this subject, was granted to Alexander Emerson in 1737; the ingredients consisted of boiled oil, mixed with poisonous substances, and applied hot; John Lewis took out a patent, in 1754, for preparing, from the juices of the American pitch pine, a species of varnish, and also for a process of distilling plantation tar, for the preservation of wood; and

Humphry Jackson enrolled a patent in 1768; his method being to boil the wood, for several hours, in a very strong solution of calcareous earth, in water, or acid of vitriol. All these early attempts were intended, more particularly, for shipbuilding purposes, and their professed object was to render soft wood, whether of home, or foreign growth, equal to the better kinds of timber.

From this period a great variety of plans seem to have been patented, more, or less directed to the express purpose of preserving timber; many of them approximating so closely to the methods of the present day, that several of the recently-expired patents might have been seriously jeopardized.

From 1808 to 1830 a great number of patents were enrolled; none of them seem to have come into general use, but they possess many of the elements of subsequent inventions, and had they emanated from practical, instead of theoretical, inventors some of them would probably have succeeded.

In 1832, John Howard Kyan took out a patent for preserving vegetable substances, by soaking them in a solution of corrosive sublimate, or chloride of mercury. This process seems only to have been used, in the first instance, for canvas, cordage, &c., but was subsequently employed for the preservation of timber. Under patents dated 1836, Mr. Kyan's process was extensively used, and, where properly applied, seems to have been effective; but the patent having got into the hands of a Company, the process was imperfectly carried out, and hence it failed to come into general use.

In 1837, Mr. Margary enrolled a patent for preserving timber, ropes, canvas, and other substances, by soaking them in a solution of acetate, or sulphate, of copper. This process has been extensively used; and when carried out, by having the solution of proper strength, and causing the timber to absorb a sufficient quantity, it will be found as effective as any of the processes of similar character; but all solutions of this kind lose their efficacy in time, apparently because the aqueous portion dries off, and the wood again takes up the humidity of the atmosphere, so that the constant alternations of wet and dry, so weaken the original strength of the solution, as to render it nearly inoperative. The experience of a large quantity of timber and sleepers, prepared by this process, has not sufficed,

so far to establish its efficacy, as to enable much confidence to be placed in its ultimate advantage.

In 1838, Sir W. Burnett took out a patent for impregnating wood with chloride of zinc. The patentee assumes as the principle of his invention, that chloride of zinc forms an insoluble compound with the albumen of the wood. In theory, such may be the case; but in practice it appears, that the solution, however good at first, becomes, as in the former instance, deteriorated in time by moisture, and consequently loses its efficacy. Sir W. Burnett has recently received from the Privy Council an extension of his patent-right for seven years; the system is now introduced by Government in several of the dockyards, and there is little doubt, that where the timber can be kept dry, it is beneficial, as tending to harden the wood, to render it partially incombustible, and to prevent the attacks of insects, which are found to commit great ravages in the interior fittings of vessels. The solution of chloride of zinc is forced into the timber, under pressure, in cylinders hermetically sealed. In heating this solution a horse-shoe boiler, on the circulating principle, is used, and is found to answer exceedingly well, both for Sir W. Burnett's and Margary's process, as by this boiler a sufficiently high temperature can be attained at a moderate cost of fuel.

In 1841, Payne's process was patented: it consists in using two solutions in succession, which mutually decompose each other, and form an insoluble substance in the pores of the wood. The earthy, or metallic solution is first introduced into the timber, under pressure; this solution is then drawn off, and the decomposing fluid is forced in; thus sulphate of iron and carbonate of soda will form oxide of iron in the cellular vessels of the wood.

This process has been largely introduced in this country, with various results. Some cases are known, where timber, prepared many years ago, is still in a good state of preservation; in others, where the operations were not well performed, the results have not been satisfactory.

In France, this process, having been more carefully applied, has succeeded much better, and it is used, at the present day, to some extent. Sufficient time has not yet elapsed to demonstrate its uniform efficacy, or to render it popular, as a preservative against the diseases, or decay of timber.

A variety of other plans have been recommended, and many patents have been taken out for the preservation of timber; but as none of them have come into general use, they are passed by, to arrive at that system of saturating with "creosote," or oil of tar, which appears to have been adopted more generally than any other process for railway purposes.

Bituminous substances appear to have formed the basis of several patents for preserving timber. That of Lewis, in 1754, has already been noticed, and many other persons have also used pitch and tar for the same purpose. John Oxford, in 1822, used the essential oil distilled from coal-tar; Francis Mott, in 1836, also describes creosote, as one of his ingredients for preparing timber; Hall, in 1838, used creosote, or essence of coal-tar, as his patent preservative for wood; and the records of the Patent-office show a great number of plans, many of them similar to each other, for impregnating timber, with some of the products of distilled coal-tar. Scarcely any of them, however, were extensively used, principally on account of want of skill in their practical use, until Bethell's patent of 1838, which is evidently founded on the same theory.

One hundred parts of coal-tar contain, when submitted to distillation, 65 parts of pitch, 20 of essential oil (creosote), 10 of naphtha, and 5 of ammonia. The oil produced from this distillation, is the creosote of commerce, now so extensively used for preparing timber. The preservative properties of this material appear to be threefold:—

First. It prevents the absorption of moisture in any form, or under any change of temperature.

Secondly. It is noxious to animal and vegetable life; thereby repelling the attacks of insects and preventing the propagation of fungi.

Thirdly. It arrests the vegetation, or living principle of the tree, after its separation from the root, which is one of the primary causes of dry rot, and other species of decay.

The Author's attention was first called to this subject in 1841, in consequence of having practised the process, to some extent, for Mr. John Braithwaite (M. Inst. C. E.), on the Eastern Counties Railway. The works, in that case, were of the most primitive and incomplete description; nevertheless they answered the purpose, and the sleepers, prepared at Heybridge, eleven

years ago, are as sound and perfect as the day they were laid down, although they are of Scotch fir, and not of very good quality. Since that time, being extensively engaged in preparing timber, many improvements have been made in the machinery and apparatus, and in the method of preparation.

Creosote is at present used for preparing timber, either under pressure in strong closed cylinders, or by placing the timber in open tanks, and keeping the solution up to a temperature of 120° to 150°, until the required quantity is absorbed. Creosote has the property of crystallizing, when the temperature is below 35°, and it becomes a hard compact mass of salts. It was in consequence of this peculiarity, and the difficulty of using it in the winter season, that heat was resorted to; this was done in the first instance by making a common fireplace at one end of the reservoir, and running a flue under the bottom. This system was, however, exceedingly dangerous, because the oil came in contact with the heated iron plate, and the temperature could not be raised beyond 70° or 75°, or only just sufficient to enable the work to be continued conveniently during the cold weather. The experiment was then tried, of allowing high-pressure steam to blow into and upon the creosote, in the reservoir; by this means the temperature was raised as high as was required, and it has continued to be used. Where a steam-engine is used, for working the pressure pumps, the waste steam can be employed to heat the creosote, by passing it through a coil of pipe, laid in the bottom of the reservoir. This mode of heating was first adopted by the Author, at Mr. Bethell's works at Battersea, and it answers admirably.

The cylinder now used, in the ordinary process, is similar to a steam-engine boiler, 6 feet diameter, and from 20 feet to 50 feet long. Formerly the end, or charging doors were made in a variety of ways, some to open inwards, some to slide in air-tight grooves, and others similar to the cover of a gas retort. Nothing, however, answers so well, as to have the cover of the full size of the cylinder, with proper fastenings, and all the joints accurately turned and fitted together; for the pressure on so large an area is enormous, and the heated oil is so exceedingly subtle, that great care is necessary to prevent leakage. Small trucks run on rails inside the cylinder, and

carry the load. These formerly ran out upon a long switch, and were then turned into a siding and unloaded. A different plan is now adopted, by making the inside lorries run out upon another larger and stronger truck of the ordinary gauge, so that by this means they can be run on to any of the adjacent sidings, to be unloaded without shifting a second time.

PLATE I. gives a general view of one of the large cylinders for creosoting timber, used at the Author's works, at Rotherhithe:—

A, the cylinder, 70 feet long, 6 feet diameter, ready to receive the charge.

B, the cover of the cylinder, ready to be carried to its position, by the crane C, and when placed on its cylinder it is hermetically sealed by the dog-hooks and screws, D.

E E E, the steam, exhaust, and force, pipes from the steam-engine,—by which heat is conveyed, vacuum produced, and pressure kept up, during the various stages of the operation.

F, the traveller, upon which the carriages H, with the binding ribs L L L, are brought into connection with the inside tram-way of the cylinder, and the siding, for loading and unloading the timbers; the arrows, G, show the direction of its motion when unloading.

I, the reservoir for the creosote, holding 16,000 gallons, and kept up to a temperature of 120° by the steam-pipes J.

K K K, three other cylinders, similar to A.

Vacuum and pressure gauges are fixed in the engine-house, to indicate the proper action of the apparatus;—accurate gauges for ascertaining the quantity of creosote used, either by weight, or quantity, are also attached to the reservoirs.

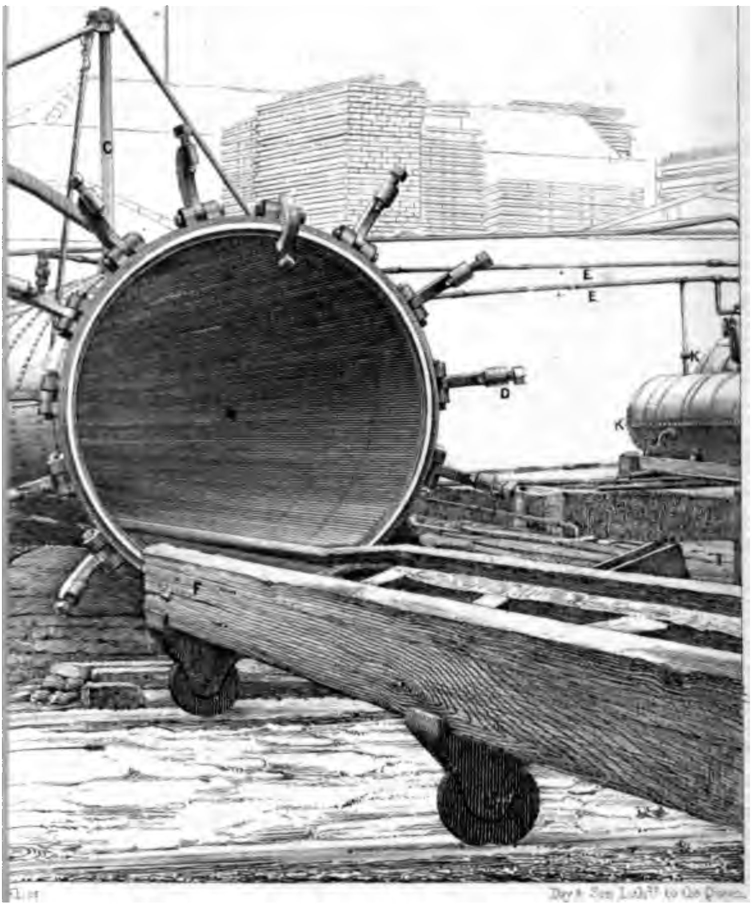
It will be observed, that the tram-roads, inside the cylinder A, and on the siding, are laid to a gauge of 36 inches, upon which the iron carriages travel. These carriages are drawn out, with their loads of sleepers, on to strong lorries, of the ordinary gauge; thus greatly facilitating the removal of the sleepers, or timber, into the bonded yards, for exportation, or to the river side, for immediate shipment; and obviating the double labour of unloading the carriages at the mouth of the cylinder, and of conveying the sleepers to a distant part of the premises.

The four cylinders at the author's works, together with their

OF TIMBER

PPARATUS.

Plate I.



Day & Son Lith[rs] to the Queen.

mechanical appliances, are capable of preparing nearly ten thousand sleepers, or about 25,000 cubic feet of timber per week.

In preparing timber, there are two ways of ascertaining the efficiency of the process; first, by fixing to the reservoir an accurately-adjusted gauge, set to a fixed point at the commencement of the operation, and by noting the consumption of oil. Secondly, by weighing two, or three pieces, or sleepers, out of every charge, both before and after the operation; the additional weight, shewing the quantity absorbed. The former plan was used by direction of Mr. Bidder, (M. Inst. C.E.,) for the works at Lowestoft Harbour; the latter plan was first used, by order of Mr. Rendel (President), for the works at Birkenhead. When the boiling process is used, the timber should be tolerably dry, and should have been exposed to a brisk wind and a hot sun, which form the most perfect mode of seasoning. The desiccation, or artificial seasoning of timber, is, however, a highly-valuable and important invention, and it is surprising, that it has not yet received stronger public approval and support, seeing, that the natural process of exposure to a dry atmosphere is not sufficient for the supply of seasoned timber demanded, and that artificial means must be employed, especially for those descriptions of wood used for decorative and ornamental uses. The process of artificial seasoning, or desiccation, will however soon become better understood, and be more generally and extensively adopted. Care is necessary, not to use too high a temperature, for when the timber is exposed to a greater degree of heat than 90° or 95°, the increased bulk of the humid matter in the timber, in its attempt to fly off too rapidly, opens up fissures on its outer surface, and produces what are called 'shakes,' and also has a tendency to tear asunder the fine ligaments and fibres, of which the texture of the wood is composed, and which, when once fractured, can never be restored. In experiments tried upon rapidly-dried timber, the horizontal strength was reduced nearly ten per cent.

The impregnation of timber, with most of the solutions, in open tanks by boiling, is to a certain extent objectionable, inasmuch as, if the timber is not previously dried, the natural juices of the wood in its substance are confined within it, and, as it were, hermetically sealed up, by the outer surface being impregnated with a new material, which is impervious to the action of atmospheric change. With all other processes this is unques-

tionably injurious to the future durability of the wood; but creosote being a perfect repellant of all humidity, even should there be some degree of aqueous matter confined within the capillary tubes, it cannot do much harm, and in process of time, even that moisture will be absorbed, and no injurious effects will occur.

APPENDIX.

PATENTS FOR PRESERVING ANIMAL AND VEGETABLE SUBSTANCES, INCLUDING TIMBER.

Emerson	1737	Treffry	1838
Lewis	1754–56	Bethell	1838
Jackson	1768	Burnett	1838–40
Donaldson	1793	Hall	1838
Browel	1808	Newton	1838–50
Heine	1808	Waithemer	1839–40–41
Durand	1810	Paris	1839
Smart	1812	Uzielli	1839–41
Murphy	1813	Holdsworth	1840
Cook	1814	Wettersolet	1840–46
Oxford	1822	Goldner	1841
Allen	1825	Gunter	1841
Magrath	1825	Payne	1841–46
Langton	1825	Jeffrey	1842–44
Newmarch	1826	Parkes	1843
George	1827	Davison	1844–47
Currie	1828	Yule	1845
Kyan	1832	Silvestri	1845
Kyan	1832	Ransome	1845
E. Mott	1836	Rinsed	1847
Kyan	1836	Cox	1847
Reignette	1836	Bethell	1848
Flockton	1836	Vernet	1849
Margary	1837		

EXPERIMENTS ON CREOSOTING TIMBER.

The specimens were twelve half-round Baltic sleepers, each 9 feet long, 10 inches by 5 inches, imported in round sticks, and sawn up.

No.	Original Weight from the Ship.	After Drying. Temp 90°. 12 Days.	After Creosoting. Pressure 140°. Temp. 100°.	After Boiling 10 Hours. Temp. 139°.
	lbs.	lbs	lbs.	lbs.
1	87½	65	123	124
2	94	86	119½	121
3	98	86	132	138
4	95	78	119	125
5	80	72	109	115
6	92	73	116	121
7	85½	75	106	113
8	84	73	108	111
9	87	72	109	114
10	79	65	97	101
11	91½	72	116	123
12	91	74	119	125

Mr. Burt, in answer to questions from the President, said, that he had purposely omitted all chemical analysis, and had restricted his paper, as closely as possible, to the practical facts of the process of creosoting, and to the consideration of the effects produced on the timber. He was so impressed with the conviction of anomalous effects being produced on the timber, prepared by the various processes under a variety of circumstances, that he determined to try a series of experiments, on pieces of timber cut from the same tree and keeping the circumstances as identical as possible; and he would, when completed, transmit the results to the Institution. At present, his impression was, that the strength of timber appeared to be increased by creosoting, if the experiment was tried immediately after the process; but that after an interval of four years, if exposed to the air, the timber lost strength; therefore he argued, that the process was better adapted for timber intended to be buried, than for that to be used above the surface; although when ample strength was allowed in the scantling, and the creosote was applied only as a preservative from decay, or from the attacks of the worm, or the white ant, he believed it would always prove successful. He condemned the London system of keeping timber in floats; it was injurious to the quality and rendered it more liable to decay; and it was more difficult to apply, satisfactorily, any system of preservation by saturation. The system of stacking, pursued at Liverpool and Gloucester was very preferable.

When it was desirable to expedite the process of saturation, by essential oils, it was necessary to remove the external ring of the timber, or to puncture it with numerous small holes. He preferred natural to artificial drying, as he believed that by the latter process the strength of the timber was diminished, and that the "shakes," or cracks were extended. He considered 8 lbs. of creosote per cubic foot, a full dose for timber for any situation; indeed it was nearly as much as could be forced in. Some sleepers which had been saturated with hot creosote, but without pressure, had taken up nearly 7 lbs. of the oil per cubic foot; they were found, after an interval of twelve years, on the Eastern Counties Railway, to be perfectly sound.

Mr. Bethell said he was very willing to afford any information, in his power, on the question of Creosoting, as the

President requested it, but whatever he could say, would only be a repetition of what he had before stated, and even published,[1] as it was well known that he had devoted much time and attention to the subject, and was largely interested, practically, in the business.

Although the means of preserving timber, from decay, had very long been an object of anxious research, and the state of the timber found in the Egyptian sepulchres and at Nineveh, furnished proof of the success of the processes of antiquity, it was not necessary for the present question, to examine further back than sixteen, or seventeen years; nor to do more than to mention the names of Kyan, Burnett, Margary, and Payne, whose processes immediately preceded the system of Creosoting, introduced by him. The three first were theoretically similar and were based on the advice of Sir Humphry Davy to the Admiralty, that the only feasible plan, of preserving timber, was to render the sap slow to putrefy, and this could only be done by entirely removing the albumen from the capillary tubes, by long immersion in water, or by coagulating it in the vessels; which could be accomplished by the exhibition of certain mineral salts; accordingly Kyan tried Chloride of Mercury, in the proportion of 1 lb. of the salt to four gallons of water; but in trials on a large scale, it was found, that the wood absorbed about 6 or 7 lbs. of the salt per load, which at 3*s*. 6*d*. per lb. (= 21*s*. or 24*s*. 6*d*. per load) was too costly; water, therefore was added to the solution, to the extent of 40 or 50 gallons per lb. of salt, and the evident consequences were repeated failures, until the system was abandoned.

Sir William Burnett used Chloride of Zinc, in the same proportion of 1 lb. of the salt to 4 gallons of water. His process lay in abeyance for some time, but had been used somewhat extensively and with advantage, for internal purposes on board vessels; it was however liable to the same objection as Kyan's, that if the solution was too much lowered, for the sake of economy, the efficacy became doubtful.

In Margary's process the Sulphate of Copper was employed, which, being a cheaper salt, was used as a stronger solution,

[1] Vide "On Preserving Timber, and on Drying and Seasoning it," by J. Bethell. 8vo. Tract. London, 1850.

and the results ought, therefore, to have been more satisfactory, but it had been stated, that all the sleepers so prepared, on the Bristol and Exeter Railway had been found decayed and had been removed. It should be remarked, that it being a property of albumen to render innocuous the corrosive sublimate combined with it, marine worms, or white ants would immediately attack wood so prepared, as they could eat the coagulated matter without danger.

Payne's process consisted, in the successive injection of two substances in solution; the first being a metallic, or earthy solution, and the second a decomposing fluid; thus filling the capillary tubes of the timber, with an insoluble substance.

Generally speaking, if the solutions of mineral salts were used, of sufficient strength, and the process was continued long enough to coagulate all the albumen, decay would be retarded for a very long period, but still the fibre of the timber was left unprotected. Now unless the fibre was also acted upon, the process of preparation must be incomplete; therefore Mr. Bethell sought for some antiseptic, which being injected into the pores, or capillary tubes of the timber, should bring it into a condition similar to the mummy-cases, or the mummies of Egypt, which were prepared by saturating them with the petroleum, or mineral pitch, found floating on the Dead Sea. Experiment proved, that Oil of Tar, or Creosote, was perhaps the most powerful coagulator of the albumen, whilst it, at the same time, furnished a water-proof covering for the fibre, and its antiseptic properties prevented putrefaction. If then the operation of injection was well performed, there was every reason to anticipate the perfect success of the system. He found, that by forcing at least 7 lbs. of Creosote oil into each cubic foot of timber, the process was perfect, and after exposure to wet and dry alternately, and in very unfavourable positions, for thirteen years, there was not any appearance of tendency to decay. A smaller quantity of Creosote might be sufficient, but he preferred adhering to that which he had proved to be effective.

He was inclined to prefer the employment of porous timber;

---

[1] Vide Minutes of Proceedings, Inst. C. E., 1849-50, vol. ix , page 40.

it absorbed the Creosote more readily,—was more perfectly saturated,—was cheaper in its first cost, and when properly prepared, would last longer than heart of oak, or any other very solid timber. The tabulated records of the creosoting process of the deal baulks, used by Mr. Rendel, at Leith harbour, showed, that as much as 18 lbs. per cubic foot, had been forced into some of the piles; the average quantity of Creosote, absorbed by the timber, was $57\frac{7}{8}$ gallons, per load, or 577 lbs. weight forced into 50 cubic feet of wood. When the exhausting process was employed, it was carried to the extent of about 26 to 28 inches of mercury.

In some cases, not more than 2 lbs. per cubic foot, could be forced into oak timber, even by the heaviest pressure. This view had been strongly combated by some engineers, who had insisted on having the hardest timber, or at least the heart wood only, prepared; there could be no doubt, that if it was practicable to apply the process, to such timber, its durability would be increased; but, it might be contended, that it was more advantageous, commercially, to render cheap and inferior timber as durable as the best quality, than, to seek to extend the duration of the more expensive sorts; especially if the process could be applied with certainty to the former and was only of uncertain result when applied to the latter. Heart wood could not be creosoted with facility, as the pores were filled with "fibrin," and the mechanical passage of the Creosote, was arrested; whilst in the outer layers, the alburnum of the wood, the pores remained open, as the sap had recently circulated freely in them, and there was therefore readiness to receive the injected oil. Mr. Bethell therefore contended, that it was desirable to use round timber with all the outer layers intact, rather than squared logs, because there would be a thicker coating of fully creosoted wood, to protect the interior, or strong heart-wood. This was an important consideration for piles, exposed to the action of the worm; and it must be admitted, that it was safer to trust to fully creosoted timber, even although originally of a porous nature, which, when prepared, would resist the inroads of insects, rather than to rely upon harder woods, whose durability was daily diminished, by the boring into it of marine insects. There was no doubt, that creosoted alburnum would last longer than the soundest

heart-wood unprepared. Besides, creosoted wood would scarcely absorb any moisture, and this alone was a great element of durability. The first sleepers sent to India, were half-round timber, thoroughly penetrated by the oil, and they had resisted both decay and the white ant. At Lowestoft harbour which was infested by marine worms, the prepared timber piles were, after four years immersion, quite untouched, whilst the unprepared timber was thoroughly destroyed. The best timber for use was young growing wood, thoroughly dried; if it was fresh cut, or had been floated, so as to saturate the pores with water, there was great difficulty in creosoting it, as the water in the pores prevented the entrance of the coal oil, even under a pressure of 120 lbs. per square inch. This led to the institution of experiments; as to the best method of getting rid of the moisture; ordinary desiccation was found to be too tedious, so he at last tried a system of smoking the timber, in a close stove, or oven, with double walls filled in with ashes, where wet timber in sticks of 15 feet, or 20 feet long, would in twenty-four hours, lose as much as 8 lbs. per cubic foot of moisture, and would if immediately plunged, whilst hot, into open tanks of creosote, absorb nearly 8 lbs. per cubic foot of oil, without pressure.

This system of smoking timber, might be advantageously used, for building purposes, as the empyreumatic acid and volatile oil, in the smoke, penetrated into the wood, and, whilst it dried it, aided in its preservation. Of course the process of Creosoting could not, on account of the odour, be applied to building timber. The process was at first performed, by putting the wood into a closed wrought-iron cylinder, 50 feet long and 6 feet diameter, from which the air was exhausted by an air-pump, and the oil forced into the pores of the wood, at a pressure of 60 lbs. to the inch, but by this plan a sufficient quantity of the oil could not be forced into very long timbers, and therefore the present improved mode was, first to dry out all the water from the pores of the timber, in the drying, or smoking-house, and then to put it into the cylinder and to force in heated oil at the pressure of 170 lbs. to the square inch. The heat was kept up, in order to prevent the crystallizing of the Creosote in the pores of the wood, during the process. Under this

system, the timber easily absorbed from 10 lbs. to 12 lbs. of oil per cubic foot. For railway works 7 lbs. per cubic foot, would suffice, but for marine work, it was better not to have less than 10 lbs. per cubic foot.

In 1848 there was a large speculative importation of sleepers, many of which remained unsold, and being stacked in the air, for some years, in the docks, became thoroughly seasoned, and many of them full of 'shakes,' or wind cracks; these, when plunged into the open tanks, were soon perfectly saturated with creosote, and absorbed a larger quantity than was at all necessary. If the Scotch larch sleepers, before being sent here, were stacked and dried, they would benefit more from the process of Creosoting, and would endure much longer.

Mr. Bethell had experienced so much difficulty in procuring a proper quality of oil of tar, that he was compelled to establish manufactories and to distil it, to suit his own purposes. Without entering into the chemistry of the manufacture, it would suffice to say, that in distilling the coal-tar obtained from the gas-works, the first product got rid of was, the ammonia which was the prejudicial substance, in the use of raw gas tar, and which dried up and destroyed the wood it was applied to; then came a light empyreumatic oil; and then the oil of tar, called Creosote, because it contained a certain amount of that substance. The product of Newcastle coal contained a quantity of naphthalin, which passed off in distillation after the naphtha; this was not liked by some Engineers; but Mr. Bethell was an advocate for its use.

The Pitch, or residuum of the distillation, on being subjected to a further process, produced coke of peculiar purity, quite free from sulphur, and earthy particles, in fact nearly approaching to pure carbon; it had been used in Birmingham for remelting iron, and it was found that the furnace could be blown clear out, without leaving any slag.[1]

---

[1] In reporting upon this coke, Dr. Ure says:—"This coke consists of carbon, nearly pure, being entirely free from the sulphur present in all coke, obtained from coals, and therefore admirably adapted to the refining of iron, into a state fit for making steel, and also bar iron of the best quality. It contains, besides carbon, merely from 3 to 4 per cent. of ferruginous ashes. It affords intense heat in burning."—[EDITOR.]

In answer to questions from Members, Mr. Bethell said it was probable, that any metallic salt, would corrode the iron bolts and fastenings, inserted into timber so prepared. The natural juices of some woods did this; as was exhibited by the specimen on the table, wherein a bolt which had united a beam of elm to one of pitch pine, was corroded almost entirely through, at the junction of the two woods.

He could only account for any difference, in the degree of saturation of various pieces of timber, from the same tank, by supposing that some were sap-wood and the others heart-wood.

He was not at all satisfied with any of the experiments he had seen, on the comparative strength of prepared and unprepared timber. Timber, whilst wet, was stronger than after being dried; and it was not improbable, that the drying and the subsequent saturation of the pores, by a foreign matter, might have some influence on the elasticity of timber, though he doubted its materially reducing the strength.

Mr. Hawkshaw said uniform strength was so important, in engineering structures, that however desirable it might be to prevent decay, if this could only be attained by the employment of a process which was liable to injure the elasticity, or to diminish the strength, it was preferable to use only the best quality of timber at a good price. He certainly would not recommend the use of sap-wood, because of its power of absorbing Creosote; indeed, for any purpose of resisting impact, or bearing strains, nothing but the best timber should be used. It would be safer, and more economical in the end, to pay greater attention to the quality of the wood than to rely on any process for preventing decay. He had laid down baulks of yellow pine in 1836, and had, on a recent examination, found them in a good sound condition, although they had not been submitted to any process. He had also examined some timber which had been Kyanized, and found that the solution of corrosive sublimate had not penetrated beyond the outer coats of the wood, and in some cases only to the depth of a little more than one-tenth of an inch. It should be stated that this was only by immersion, and not applied under pressure.

On a line of railway where he had recently replaced a quan-

tity of longitudinal timbers, originally of good sound yellow pine baulk, the timber was generally perfectly sound and free from decay, although from the scantling being too light for the traffic, the rails had worn into the timber to a considerable depth, and had rendered necessary the removal of the baulks. If for such uses, good sound yellow pine was selected, without sap-wood, and exposed for a sufficient period to light and air, it would last longer, free from any appearance of decay, than it would resist the crushing effect of the force travelling over it; therefore, it might be stated, that Engineers could not adopt a more fatal system than to use inferior timber, merely because it would readily absorb creosote, or any other antiseptic.

He had tried all the principal systems, and would not generally employ any except Creosoting. Kyan's was inefficient, Burnett's was not satisfactory, and Payne's rendered the wood brittle. He had certainly never seen an instance of decay in creosoted timber, even in the most unfavourable position; still he did not think it was practicable to force any solution, by pressure, into the pores of timber, without injuring its elasticity and strength; how far the same effect would be produced by the system of absorption of Creosote by hot timber, described by Mr. Bethell, it was not possible to say without direct experiment.

Lieutenant Jackson, R.N., thought that erroneous opinions were entertained of Sir William Burnett's process; it was entirely chemical. The influence of the chloride of zinc appeared to pervade the entire log of timber, and he had never seen an instance of metallic salt having been removed from the wood, after it had been properly saturated.

Mr. J. T. Cooper said the decay of wood by dry-rot might be traced to the putrefying of the sap, or, in other words, to the process of the circulation of the sap, as when growing, not having been arrested. This was done either by soaking timber in water to wash out the sap,—by exposing it to the sun and wind, to dry up the sap naturally, or by baking to dry it up artificially; or else by injecting some metallic salt to combine with the albumen, or some antiseptic, or other substance; such were all the processes he had examined.

Many specimens of variously-prepared timber had been submitted to him professionally for examination; among others, some portions of Kyanized piles from Dover harbour. After nearly three years immersion in the sea, no traces of corrosive sublimate remained in them. He had also examined many specimens of timber, canvas, cordage, &c., which had been "Burnettized," and, after long immersion in cold water, he always found evidence of the chloride of zinc. Portions of timber so prepared were burned, to destroy the fibre, and in the ashes he found oxide of zinc. He then took some sawdust, moistened it with the solution of chloride of zinc, dried it, charred and consumed it, and in the residuum he found traces of the oxide of zinc, showing how intimate was the combination of the metallic salt with the timber. He believed there was a great facility in the albumen for combining with the chloride of zinc, and that the compound formed was not soluble in cold water.[1]

Captain MOORSOM had tried the processes of Kyan and Margary somewhat extensively; the first required great care, and even then the results were not satisfactory. The preservation of the timber was not insured, and the transverse strength was injured to the extent of three, or four per cent., although the process was not performed under pressure. To satisfy himself on this point, he caused some experiments to be made in 1839, placing them under the charge of Mr. G. D. Bishopp.

The corresponding pieces, between which the comparisons were made, were cut out of the same plank, each side by side with its fellow. One of these pieces was then prepared by Kyan's process, in the usual way, but without pressure, and the other was left in the natural state.

The transverse clear bearing was, in every case, 36 inches.

The length of each piece was 42 inches.

The weights were suspended from the centre of each piece, in ordinary cwts., half cwts., and lbs.

---

[1] Vide "Account of Sir W. Burnett's Process for the Preservation of Timber, Canvas, Cordage, &c." 8vo. Tract. London. No date. And "Report of the Proceedings and Evidence before the Privy Council on the Petition of Sir W. Burnett, for the extension of his Patent," &c. 8vo. Tract. London, Feb. 7, 1852.

The following were the results:—

AMERICAN YELLOW PINE.

Pieces in the Natural State.			Pieces prepared by Kyan's Process.		
Sizes.	Marked.	Broke with.	Sizes.	Marked.	Broke with.
Sq. In.		lbs.	Sq In.		lbs.
1¼	A	232	1¼	C	182
,,	B	252	,,	D	252
,,	F	308	,,	G	294
1½	I	539	1½	H	525
,,	L	476	,,	M	469
1	Q	161	1	P	154
ARCHANGEL DEAL.					
1	5	210	1	6	182

The piece marked C broke suddenly, at a knot near the centre, and in any resultant, it seems proper to throw this piece, and its fellow, marked A, out of the scales.

The result, in the aggregate, of the American pine (exclusive of the pieces A and C), shows that the ratio of strength, in the natural state, was as 1,736 to 1,694 in the prepared state, or as 1,000 to 976.

And in the Archangel deal, the ratio of strength, in the natural state, was as 1,000 to 867, in the prepared state.

He was inclined to think well of Margary's process, as timber which had been left in copper mines, and had been saturated with the mine water, appeared to be very hard and almost indestructible.

Mr. WALKER said that in the year 1837-38 he caused an apparatus to be erected for Kyanizing the sleepers used on the Hull and Selby Railway; the process was first by exhaustion, and then under pressure. He had every reason to be satisfied with the result, as none of the sleepers had shown any symptoms of decay. He believed that dry-rot in timber was a local disease, and if the diseased parts were once cleared away, the return of the disease need not be feared. This was frequently shown on board vessels, where, after a searching investigation and cutting away of faulty planks and timbers, the dry-rot was completely eradicated. He believed the best preservative for timber was the natural process of air-seasoning, by being

stacked for a considerable time in the docks. 'Greenheart' timber, unprepared, was generally found to resist the marine worms, even in the worst situations.[1] An instance was on record of a ship, in the port of London, having nearly the whole of the bottom planking eaten into by worms, with the exception of one plank, which proved to be of Greenheart timber. As a general rule, the worm was a more serious enemy to deal with than the dry-rot.

Mr. RENDEL,—President,—said that Mr. Hartley, had great confidence in the durability of Greenheart timber, which he used for sheathing dock gates, for the cills of sluices and other purposes where the failure of ordinary timber might produce serious effects. It was however unfortunately so expensive, costing from 4*s.* to 5*s.* per cubic foot, that its use for piles, or other large timber works, was almost prohibited.

He recalled to the recollection of the Members some specimens of timber from Western Australia, called "Jarrah" wood, which had been exhibited at a meeting of the Institution in the Session 1849-50.[2] That wood was stated to possess the property of resisting the worm and the white ant; to be easily procured of any dimensions, and at a reasonable cost; if that statement was correct, the announcement was important, as the introduction of such a timber would be very useful to engineers and naval architects.

Mr. BRUNEL, V. P., had employed the various processes very extensively, and latterly he had used Sir William Burnett's system, as he had found it efficacious and less expensive. It would however appear, that but little was positively known of the relative value of the various preparations, or of the mode of using any of them. Instances were given of unprepared yellow pine enduring for seventeen years without decay, and then only being removed because it was destroyed by the weight of the traffic passing over it. The best antiseptic preparation could not have accomplished more than that. It did however appear, that the injection of Creosote enabled the timber to resist the marine worms. Mr. Brunel had found this in piles so prepared and used at Plymouth and on that coast, which was

[1] Vide "Minutes of Proceedings, Inst. C.E., 1840," vol. i., page 84.
[2] Vide "Minutes of Proceedings, Inst. C. E., 1849-50," vol. ix., p. 40.

much infested by the worm. The metallic salts did not appear to have the same effect on animal life. Perhaps this might, in some degree, be attributed to insufficient preparation, or more properly speaking, to some amount of carelessness in the preparation, or the use of indifferent material. In spite of all assertion to the contrary Mr. Brunel must maintain, that he had seen some very bad Creosote and had prohibited its use; as he was convinced, that unless good Creosote was employed the timber was damaged.

His present experience induced him to prefer the use of chloride of zinc for all purposes, under cover, and creosote for out-of-door use. He was of opinion, that the former, when properly applied under pressure, did enter the heart of the timber, and as the latter was readily absorbed by the sap-wood, whenever it was desirable to prepare the timber thoroughly, and expense was not a material object, both processes should be employed; the salt first and the Creosote afterwards. Dry-rot, the effect of damp, and the attacks of the worm would thus be equally guarded against. Thorough preliminary drying was essential under all circumstances.

It was stated, that Dr. Faraday had found traces of corrosive sublimate in the heart of a piece of pine timber 26 inches square, prepared by Dr. Kyan's process under pressure.

Mr. Vignoles corroborated the statement, as to the durability of good, well selected, dry yellow pine; he had found unprepared sleepers, laid under such circumstances, perfectly free from decay, after being down for sixteen years, and they had only been removed because they were literally crushed by the traffic; that alone, by inducing shakes which let in the water, would have sufficed, with an inferior quality of timber, to have caused decay. It appeared to be an admitted fact, that the injection of Creosote did effectually preserve the timber from decay and enable it to resist the attacks of marine worms; these were valuable points, and as it was stated, that previous drying rendered the process more effective, he would suggest the employment of steam of high density (vapeur rouge) at a temperature of 400° or 500° Fahrenheit, driven through the cylinders at considerable velocity, so as to pass among the logs of timber.

Mr. Bethell had already directed his attention to that

system of desiccating, and had in fact incorporated it in one of his patents in 1848, but from further experience he was inclined to prefer his present stove; it was less expensive, and more easy to work than the high-pressure steam, and he attributed a powerful effect to the antiseptic property of the smoke in the drying stove.

Mr. Davison, through the Secretary, said he must offer his testimony in favour of the system of creosoting timber, for all purposes where it was exposed to wet. He was of opinion, that the process of desiccating was most essential for the success of any preparation, as it was only by the removal of the sap and moisture from the capillary tubes of timber, that it could be preserved from decay. Impressed with this, as an axiom, he had paid great attention to a process for desiccating timber, by means of heated air, and would explain to the meeting a slight sketch of the system, and of the effects produced.

The desiccating process, consisted in rapidly impelling currents of highly-heated air through a chamber, or chambers containing the wood; spaces being left between the ranges, or tiers, for the heated air to act uniformly upon all sides of the timber; the moisture, as it was evolved from the surface, was instantly driven away through openings left for that purpose, the wood remaining in the chamber until it was ascertained, by weighing a sample from time to time, that the whole of the aqueous matter had been expelled from its pores. This was the substance of the process; but, the practical and successful working of it depended upon a variety of details and circumstances, which he would endeavour to describe.

1st. Different woods, and different thicknesses of wood, required different degrees of heat.

2nd. Hard woods, and thick pieces of wood, required a moderate degree of heat, from 90° to 100° Faht.

3rd. The softer woods, such as pine, might be safely exposed to 120° or even to a higher temperature; and when cut exceedingly thin and well clamped 180° or 200° Faht. had been found rather to harden the fibre and to increase its strength.

4th. Honduras mahogany, in boards of one inch in thickness, might be exposed, with advantage in point of colour, beauty, and strength, to a heat as great as 280° or 300° Faht.

As a proof of this, a slab of Honduras mahogany 1½ inch

thick, cut fresh from the log, was wholly deprived of its moisture, amounting to 36 per cent., by exposure to the temperature of 300° for 50 consecutive hours.

This was however only stated, to show that a high degree of heat might be applied, when for some purposes it was considered desirable, as for instance, for cabin-fittings near to boilers, or for furniture for tropical climates, &c., but in practice it was found, that from 115° to 120° enabled almost every kind of wood, in slabs of moderate thickness, to go on steadily and safely towards complete desiccation, in a comparatively short space of time, for instance, one week to every inch in thickness, within a certain limit, say up to 4 inches thick in 4 weeks,—6 inches thick in 7 weeks,—8 inches thick in 10 weeks, and so on in something like that ratio. This, however, supposed the current to be kept up only during the day of 12 hours, and then the chamber to be closed until the following morning, that being the customary mode of working, but in the example just quoted that which ordinarily occupied nine, or ten days, according to the usual practice, would be done in little more than two days and nights, under a continuous and increased temperature. By a proper arrangement of chambers for different woods, and various thicknesses, and likewise a proper system of adjusting the temperature of the currents, suited to continuous day and night work, almost every description of wood might be thoroughly seasoned, in little more than three days, on an average, for every inch in thickness. Many instances of exceedingly quick, and at the same time, successful seasoning, could be adduced, but there were some woods which would not admit of such treatment. English oak required considerable care. Such timber should never, under any circumstances, be exposed for any great length of time to a higher temperature than 105°. A higher heat was proved to act upon the gallic acid, or on the fibres, in some peculiar way, so as to cause internal fissures, as though numerous small explosions had taken place; but such appearances did not present themselves, until after several days' exposure to the heated currents, and no appearance of fissures, or cracks were to be found on the external surface.

Heat without a current, like that of an oven, and heat in a moving state, were totally different in their effect upon wood. In the one case the fibre was rendered short, brittle, and weak,

in the other, all that was valueless was driven away,—the albumen became solidified, or coagulated, and the fibres were rendered much stronger and more rigid.

It had been found, that 100 feet per second was the best velocity, and, with a proportionate area of inlet pipe, was a sufficient volume to cause a complete displacement of all the air and moisture in the chamber, in three minutes; or, in other words, supposing a desiccating chamber, to contain 30,000 cubic feet, it was usual to propel into it 10,000 cubic feet of air per minute; always taking care, that the area of the outlet, or outlets for the escape of the moisture, should be something beyond the area of the inlet; in this system no moisture could under any circumstances remain lodged about the timbers, but was instantly expelled through the ventilating apertures.

One of the most convincing proofs of the efficiency of the system was to be found, in the fact, that Her Majesty's Board of Ordnance had, during the last four years, employed it for seasoning nearly the whole of the gun-stocks required for the service. It was formerly the practice for the Government, previous to the adoption of the process, to have about 400,000 stocks in the course of seasoning, all requiring to be turned over once, or more every year, to prevent the ravages of the worm, or decay; whereas they could now, by the use of the desiccating process season about 10,000 stocks in the course of two, or three weeks, at a very trifling cost.[1]

---

[1] In a Report, dated from the Tower, June 2, 1849, Mr. Lovell, H.M. Inspector of Small Arms, states:—"I will candidly confess, that from the failure of all the experiments I had previously made, or read of, for seasoning wood, by means of steam, hot air, boiling water, &c. &c. (and they had been numerous, and most carefully conducted), I was prepossessed with the idea, that a large proportion of those first sixty stocks would be spoiled; but at the same time, I was determined that the desiccating plan should have a full and fair trial: one half of the number were quite fresh cut, and green wood; the other moiety had been about twelve months in store; the total weight, before the process, was 536 lbs. 9 oz., and after ten days' exposure to a current of air, heated to 110° or 114° Faht., that weight was reduced to 413 lbs. 14½ oz.; that is to say, 122 lbs. 10½ oz. of moisture had been driven off. Some of the stocks had been purposely selected with sun cracks in the butts, and other faults; for I expected, that those cracks and faults would be exaggerated, by the heat of the chamber; but the result was not so—on the contrary, they were closed, considerably, behind the marks that had been stamped upon the ends of them, before they were put in, and the whole number of stocks came out in good condition, and fit for immediate use. [It

In laying down the ornamental flooring of the New Coal Exchange, about three years since, where green and almost wet woods were used, in no case did one out of the 4,000 pieces, of which the floor was composed, exceed ten days in seasoning. The floor had stood well—no part having exhibited symptoms of shrinkage, except in a few instances where the workmen were short of material, and in the hurry had to make use of such as had not sufficient time allotted for its seasoning. The floor had cost nearly £800.

It was a well-known fact, that flooring-boards, after being down for upwards of a century, on being taken up, and having their edges "re-shot," would again shrink, nearly as much as though they had never been seasoned. This must arise from the fact, that all woods received an external hardening, or casing, from exposure to the atmosphere, which prevented the whole of the moisture from escaping; and thus after the skin was removed, and the wood was allowed to breathe again, another shrinkage ensued. Not so with wood which had been exposed to an artificial mode of seasoning, under a continuous artificial current and temperature. This point had been

"It would be tedious to go into the detail of all the other tests that the process has been put to; it may suffice to say, that after every possible trial, all my doubts have been removed, by the only safe guide, that of experience; and it gives me great pleasure to be able to state, that the desiccating process, as applied to the seasoning of walnut wood for musket stocks, is entirely satisfactory. The wood is better seasoned, than when dried in the open air; 1st. Because the albumen, being dried in the pores and capillary tubes, renders the fibre stronger and less liable to absorb moisture. 2nd. The wood is stronger, tougher, and of course more capable of withstanding the effects of violent vibration, from the lateral adhesion of the fibre being better preserved. 3rd. It works smoother and more waxy under the chisel, and has less tendency to 'speel' and crumble away, which is generally the great fault of steam-dried timber.

"I have now worked nearly 30,000 desiccated stocks, none of which had been under the process more than twenty-one days, and my opinion is very decided, that the wood is more thoroughly seasoned, and with much greater certainty, than if it had been merely exposed to the open air, in the usual way, for three, or four years.

"The Desiccating Chamber, erected in the Royal Manufactory at Enfield, continues in full activity. The heat is kept down to a medium degree between 90° and 100°; and at this temperature, it delivers the stocks, perfectly seasoned, in fourteen to sixteen days, according to the quality of wood—whether of sap, or heart; and I propose to subject the whole of the stocks to it in future, whether they have been air-dried previously, or not; in order to make sure that the whole shall have been equally seasoned."

accurately tested, and it was found that no second shrinkage occurred, after being properly treated with the heated currents.

A number of very interesting experiments were made for the Admiralty, but in consequence of want of attention to minutiæ, although they were sufficiently convincing for all who followed the course of experiments, they could scarcely be given intelligibly otherwise than by diagrams, which were exhibited.

As to the effect of currents of hot air upon wood: about six years ago, in a chamber erected for seasoning wood, there were placed a considerable number of bearers, to act as supports for the timber sent to be seasoned. These bearers were still in use, after being subjected night and day for that period, if not always to the currents, at all events to 115° or 120° of heat, which the chamber invariably stood at. All were found to be perfectly sound and in first-rate condition: one of them a piece of Riga pine, showed considerable external wear and tear; but without in the slightest degree being affected in the inside; another piece of American elm did not show any external rubbing, or wear and tear. They proved very decidedly, that the process alluded to, did not, though continued for such a length of time, injure in the slightest degree, the fibre, or strength of the wood.

M. Boutigny (d'Evreux), through the Secretary, said it was admitted, that the decay of timber arose from the action of humidity and of the oxygen of the atmosphere, which penetrated to the heart by absorption and infiltration; this action was active upon the fibre, and engendered a slow and spontaneous process analogous to what had been designated by Liebeg as 'eremacausis.'

These elements of destruction appeared to act chiefly from the ends of the timber, following the natural course of the sap. If then, it was argued, after thoroughly depriving the timber of moisture, the ends of the pores were hermetically sealed, all absorption would be prevented, and there would not be any tendency to decay. Acting upon this principle Mr. Boutigny had, in conjunction with Mr. Hutin, introduced a system, chiefly adapted for beams and timbers for buildings, the extremities of which were peculiarly liable to decay from dry rot, where they were fixed into the walls, or where there was not

any circulation of air. The process consisted in desiccating the timber, partially charring the ends, and then immersing them in oil of Schistus, or some analogous substance, which penetrated with rapidity; then after blazing off the ends, they were plunged, for the length of a few inches, into heated pitch, tar, or gum-lac, the mastic was slightly absorbed by the pores and fibre, and the ends were completely sealed against the entrance of either moisture, or air. If considered necessary, it was, under certain circumstances, advantageous to pitch the whole surface of the timber.

They had been induced to introduce this process, because they were convinced of the inefficiency and of the generally prejudicial effects of the ordinary methods of preserving timber.

Corrosive sublimate (Chloride of Mercury) was expensive, and produced ill effects on the health of persons inhabiting buildings, where the timber so prepared had been used.

Arsenious acid was cheaper, but was so dangerous as to have been abandoned. The chlorides of calcium, of sodium, and of zinc, were deliquescent, and there was some doubt as to their chemical action.

The sulphates of copper and of iron, had been much used; the former was dangerous, and moreover it was apt to corrode the fibre of the wood and thus to render it permeable to moisture; also by the combination of the oxygen with the wood and the consequent disengaging of the sulphuric acid and its action on the fibre, the strength of the timber was liable to be injured. The same objections held good, to a certain extent, against the sulphate of iron; it was well known how soon a spot of iron-mould became a hole in a piece of linen, which was composed of vegetable fibre.

Of all the systems hitherto proposed, that of injecting resinous oils was the most rational, and scientific, although the most ancient of which there was any trace, and it did appear, as far as M. Boutigny's limited knowledge of English permitted him to judge, that the statements made in the paper and by Mr. Bethell were calculated to be very useful. He regretted being obliged to make his communication in French, but trusted to the indulgence of the Members in receiving the Secretary's translation of his remarks.

LIEUTENANT JACKSON, R.N., exhibited specimens of timber,

rendered uninflammable, by Sir W. Burnett's process (Chloride of Zinc). It was stated, that in the most intense fire, timber, or even linen, so prepared, could only be charred, and would never burst into flame. This process was calculated to be very useful in shipbuilding, and was now extensively used in H. M. Navy.

Mr. Bidder, had been much interested in discovering a process which would effectually protect timber from the worm, as the harbour at Lowestoft was, perhaps, more infested with marine insects than any other port in England. He, therefore, examined carefully into the results of all the systems. Mr. Gibbons assured him, that Kyanized piles only resisted for one year, at Kingstown harbour; after that time they were speedily destroyed. Payne's process utterly failed at Fleetwood, and the reports from other quarters, as to the other processes, were so discouraging, that he resorted to the use of Creosote. At the beginning, some of the piles were inefficiently operated on, and the worm had made partial inroads, but they soon got into a good system, and had been very successful. For piles he would advise a longer time, than usual, being devoted to the process, in order that the heart-wood might be penetrated. He was now trying the system of boring an inch-hole vertically to some depth in the centre of the pile and keeping it constantly supplied with Creosote. He thought this would tend to the preservation of the piles.

On the Northern and Eastern Railway the prepared sleepers, laid twelve years ago, were still in excellent condition; indeed if it were always possible to command a good quality of timber, and proper precautions were taken, in draining beneath them and admitting the air, the timber would last a very reasonable length of time, but when works were required to be executed in great haste, timber of inferior quality was brought on to the ground and was of necessity used, to avoid the greater loss, by the non-performance of the work within a given time; thus such a system as Creosoting had become so useful, as by it inferior timber was rendered even more durable than good wood.

Mr. Errington said the result of his experience was, that if really good Scotch larch was used for sleepers, with even ordinary care in draining the ballast, the timber would be found in a

good state, as to soundness, at the end of fourteen years, and by that time the seats of the chairs would probably be so galled and worn away, as to require the renewal of the sleepers.

Mr. RENDEL (President) said all Engineers having to erect timber structures must be interested in this subject, as it was not always practicable to obtain a proper quality, therefore it was a great boon to have, by some process, the means of giving durability to inferior qualities of wood. The marine worm was a sad foe to timber structures on some parts of the coast, and in many of the estuaries. Such was the case at the Royal Pier at Southampton, and there the 'Terebrans' had, within four years, reduced pine baulks of 14 inches square to about 4 inches; all kinds of preparations had been tried, but hitherto unsuccessfully. In order to test the efficiency of Creosote, he had, in 1848, requested Mr. Doswell the resident Engineer, to have attached to the piles which were most eaten by the worm, some specimens of timber, prepared by the processes of Payne and of Bethell, as such a practical test was more valuable than all theory. The result was exhibited by the specimens laid before the meeting. The pieces of fir timber had been attached to the piles on the 22nd February 1848, at the heights of low-water of spring tides; low-water of neap tides; and high-water of neaps. They were detached in January 1853, when it was found, that whilst the pieces of unprepared and the 'Payneized' timber were entirely converted, by the worm, into masses of disintegrated fibre, the Creosoted timber remained perfect and was untouched by those marine insects.

As it was very desirable to have an opportunity of testing the value of a system of preparing timber, the President offered permission to any one, to attach, in an identical position, specimens of timber prepared by any process, and to bring them, after a given time, before the Institution, to enable the merit of the system to be practically ascertained.

He was so convinced of the superior efficiency of the Creosoting process, that he devoted great attention to its being thoroughly performed, at Leith and on other works under his direction, and he recommended Engineers not to be satisfied with the ordinary mode of Creosoting; but to have the timber weighed into and out of the cylinder, to test the absorption by the actual increase of weight, and not to consider the process complete, unless 7 to

10 lbs. of Creosote, by weight and not by measure, had been taken up by each cubic foot of timber.

Greenheart timber, which had been mentioned, was full of a powerful empyreumatic oil, to which was due the power of resisting the attacks of marine insects. In Demerara it was familiarly called 'torch-wood,' because it burned as freely as pitch-pine torches. It cost in England about 4*s.* 6*d.* per cubic foot; whereas creosoted pine cost about 2*s.* per cubic foot.

January 18, 1853.

JAMES MEADOWS RENDEL, President, in the Chair.

The discussion upon the Paper No. 881—"On the Preservation of Timber," by Mr. H. P. Burt,—being continued, was extended to such a length, as to preclude the reading of any other communication.

January 25, 1853.

JAMES MEADOWS RENDEL, President, in the Chair.

At the conclusion of the discussion "On the Preservation of Timber," The PRESIDENT directed attention to the Dublin Exhibition, and Mr. C. P. Roney, Assoc. Inst., C.E. (the Secretary), stated, that the undertaking was progressing most favourably, the original size of the building would be nearly doubled, and to meet the additional outlay, Mr. Dargan had increased his donation from £20,000. to £50,000.

It was believed, that the department of machinery in motion would be quite as interesting and attractive as that in the Great Exhibition of 1851, in London.

The Society of Arts (of London) had determined, that their East Indian Exhibition and all the influence of their body should be transferred to the Dublin Exhibition. There would also be a Mediæval court, and an Archæological collection, which would show that Ireland, though of late years not progressing

so rapidly as this country, had in former times; possessed high attributes of civilization. There would also be a fine collection of ancient and modern pictures of every school. Mr. Roney solicited the aid of the Members towards the Exhibition, by the loan of models, whether working, or stationary, and of works of art, of which he promised, that great care would be taken.

No. 883.—"On the Construction of Fire-proof Buildings." By James Barrett, Assoc. Inst. C.E.[1]

The construction of fire-proof buildings is, probably, a subject of more direct interest to the Architect, than to the Engineer. There are, however, many structures, connected with docks, arsenals, railways, and other public works, more directly under the direction of the latter, in which an economical system of fire-proof construction would often be desirable; and a strong feeling now prevails, that some remedy should be provided for the loss of life and great destruction of property resulting from the general use of timber. The construction of buildings, on a principle almost entirely excluding that material, may, therefore, prove a subject of interest; and its importance to society at large is sufficient apology for its introduction, at a meeting of the Institution, where it has been already cursorily referred to. The former discussions on fire-proof construction have, however, been limited to the advantages and defects of the cast-iron girder and brick-arch system, as applied to the floors of warehouses and mills; to which particular class of buildings the application of a fire-proof principle has, until within a very recent period, been mainly confined, chiefly because the girder and arch system is not adapted for general purposes, and none other is familiarly known. The importance, however, of introducing some method of fire-proof construction, admitting of a wider

---

[1] The discussion upon this paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

A Telford Medal was awarded to the Author, for this paper, at the Annual General Meeting, December 1853.

and more general application, has now been fully recognized; and the chief object of the present paper is to describe a system, applicable, at a very low rate of cost, not only to structures of the above description, but to all classes of public edifices, as well as to private dwelling-houses and domestic buildings.

The general employment of timber, for the purposes of construction, has been sanctioned by custom, chiefly on account of its cheapness, and its facility of adaptation in a building; and these qualities have rendered its employers, to a great degree, regardless of certain disadvantages attending its use—such as its injurious effects in weakening the walls of a building, when employed as joists, wall-plates, &c.—its tendency, when not properly seasoned, to shrink and produce cracks in the ceilings and the floors—its liability to the attacks of dry-rot, and the ravages of insects, and its affording also a harbour for vermin—and lastly, its great combustibility, increased, to a fearful extent, by its being frequently placed in close proximity to flues and fire-places, often supporting a smouldering combustion for a lengthened period, and then bursting into flame on the first access of air to the locality.

The extent to which buildings are exposed to latent danger, from the continued action of fire, or heat from flues, &c., upon the timbers, is comparatively little known; but sufficient has been made public, to show, that, with the use of timber-joists for floors, very few buildings are secure. The great loss of life, indeed, and the vast destruction of property, resulting from the general use of inflammable materials in the structure of buildings, would, if there were not strong reasons against such interference, go far to justify some legislative enactment on the subject, and it would be easy to show, that the public would be gainers by such a step. But as this would be a departure from the principle of non-interference, so wisely insisted upon in these matters, in this country, the initiative must be taken by the members of the engineering and architectural professions, who are the parties best qualified to judge of the merits of such improvements in construction, as may be offered to their notice; and "if," as has been well remarked, "buildings may be rendered far less inflammable, than they are usually made,

without material increase of cost, whereby life will be less exposed to danger, and property be better protected from the destructive action of fire, the propriety of adopting arrangements to that effect will not be denied, even by those who would refuse their consent to the imposition of rules, to compel their adoption."[1]

The loss arising from fire may be covered by insurance, and the proprietor may get his building replaced, at no direct cost to himself; but the losses resulting indirectly from other causes, such as the suspension of his business, the destruction of his books, and the general confusion into which his affairs are thrown, are frequently far more serious than the loss of the building itself; while, in the case of manufactories and similar buildings, the evil, as regards the workmen, is of still greater magnitude, as they are often deprived, for a considerable time, of the opportunity of earning the means of subsistence, and thus frequently become a burthen upon the public.

Indeed, the many disadvantages resulting from the use of timber would render it a matter of surprise, that its employment should be so universal, were it not at the same time considered that, until recently, it had yet to be demonstrated that any other material could be substituted, without incurring a greatly-increased expense.

The iron-girder and brick-arch system, sometimes employed in mills and warehouses, and occasionally introduced into large public buildings, while demonstrating, by its employment, the opinion entertained of the importance of fire-proof construction, has shown, also, that such an increase of cost attends its adoption, as tends to restrict, and in many cases to prohibit, the employment of that method of building; and if the same results can be secured by the adoption of another system, which does not involve the same increase of cost, and moreover is free from the objection of imposing that lateral thrust on the walls, which is the case with brick arches and cast-iron girders, that system must be worth consideration.

In the use of girders and arches, one prominent disadvantage

[1] *Vide* Prof. Hosking, on "The Regulation of Buildings in Towns," 8vo. London: Murray, 1848.

is the danger, in the event of the fracture of one of the main girders, of the whole structure being instantaneously destroyed, from the fact of each arch, in any one line, being mainly dependent on its neighbour for support. A detailed account of the results of such an occurrence is given in the "Report of the Fall of the Cotton-mill at Oldham," by Sir Henry De la Beche and Mr. Thomas Cubitt, in 1845.[1] This accident occurred, while one of the arches, which had settled, was being replaced, and it commenced by the breaking of one of the cast-iron beams, in the upper floor, in consequence of the lateral thrust of an adjoining arch. The breaking of this beam was immediately followed by the successive yielding of all those adjoining it, and the consequent falling of the arches which these beams supported. "This happening on the upper floor," the Report goes on to say, "there is little difficulty in conceiving, that the mass of bricks and iron, thus suddenly thrown upon the floor beneath, would crush it; and this again falling on the third, and so on, the accumulation of falling matter would be such, from floor to floor, that after the failure of the upper floor (that in which the arch was under repair), the whole would appear to fall almost instantaneously, or in one great crash." The crash, it appears, was almost instantaneous; the whole building, consisting of five stories, apparently giving way at the same time, and causing the death of twenty persons.

Now, although, in this particular instance, there appears to have been some want of sufficient strength in the beams, yet the accident is clearly traceable, and is in fact assigned, to the effect of the lateral thrust of the arch upon that particular beam, which was exposed, and but partially protected; and even admitting that a greater degree of strength in the beams, might have lessened the extent of the damage, yet it must be conceded, that a system liable to produce such calamitous results, cannot be regarded with that degree of confidence which should be felt, where so many lives and so much valuable property are at stake. Independently of the danger arising from the breaking

[1] *Vide* "Report on the Fall of the Cotton Mill, at Oldham, and part of the Prison at Northleach," folio. London: Clowes and Sons. 1845.

of a girder, the slightest sinking of the foundations, or disturbance of the walls, may, at any moment, render an arch insecure, and thus peril the safety of the entire building.

Looking then at the disastrous effects which may result from the employment of cast-iron girders and brick arches, it becomes a subject of interest to inquire how far these effects may be avoided, without sacrificing any of the advantages which that method of building is acknowledged to possess.

The objects sought to be accomplished by the system of fire-proof construction, about to be described, whether applied to mills, warehouses, public buildings, dwelling-houses, or other structures, are:—To render each floor, as well as the roof, of the building, completely fire-proof, so that fire can neither be communicated from one story to another, nor be introduced into the building, by burning away the roof; to avoid all lateral thrust, or weakening effect, upon the walls; and to distribute the weight over them, instead of concentrating it on certain points; to secure the building from the attacks of dry-rot; to give increased solidity, firmness, and durability to the structure; to render the floors practically sound-proof, when finished with a boarded surface; and to combine these advantages with great simplicity and economy of construction, and with a less thickness of floor than is usually required.

These objects are accomplished, by forming the floors of the building, of materials as imperishable as the walls themselves; the leading features of the system being, the substitution of girders and joists, either of wrought, or of cast iron, for those of timber, and the employment of layers of incombustible materials, supported by and consolidated with the joists; the whole, when combined, forming a solid fire-proof foundation, adapted to receive a finished surface, either of cement, gypsum, asphalte, tile, slate, stone, or other material; or upon which foundation the ordinary boarded surface may be laid down upon light sleepers, or bevelled fillets.

The principle of construction, as applied in its most simple form, is shown in Figs. 1 and 2.

Fig. 1 is a section across the course of the joists, with a cement, or other similar surface.

Fig. 1.

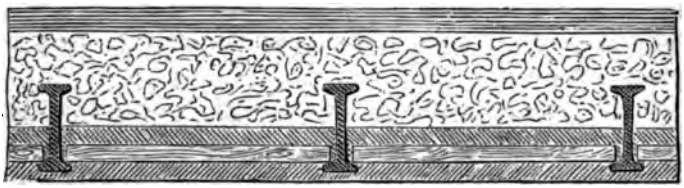
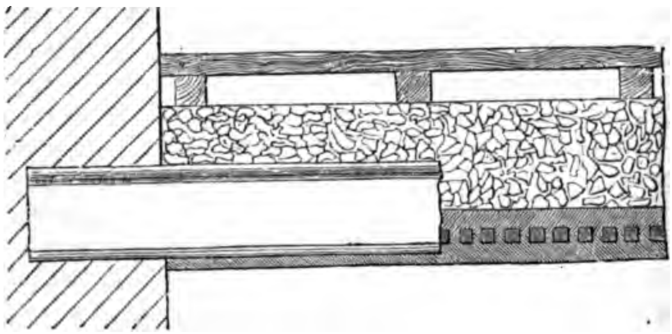


Fig. 2 is a section between and in the direction of the joists, with a boarded surface, the iron joist being broken off, to show the construction of the floor.

Fig. 2.



The joists are fixed as the building proceeds, their ends being firmly built into the walls; and the floor is afterwards formed, by first laying light rough strips of wood across from joist to joist, bearing on the bottom flanges, and having narrow spaces between them.—Upon these is spread a layer of coarse mortar, which is pressed down between the strips, so as to form, with them, a rough and uneven surface, for the pricking-up coat of the ceiling, the subsequent application of which thoroughly imbeds the strips in mortar. A layer of concrete is then applied, of the requisite thickness to insure the necessary rigidity in the floors. This thickness will vary, according to the width of bearing, the required degree of strength in the floors, and the nature of the building; and when the thickness is considerable, it is applied in two separate layers, so as to facilitate its drying. The ceiling is attached by means of the key afforded

by the rough strips and the coat of mortar over and between them, and it is put on of such a thickness as to perfectly imbed the flanges of the joists, and thus to protect them from the action of fire from below.

A fire-proof foundation is thus formed, which, when thoroughly consolidated, by the perfect setting of the concrete, is of great strength and rigidity, while the pressure upon the walls is directly vertical. The finished surface of floor is applied, when the concrete is set and dry.

The joists, when made of wrought iron, are rolled of a form combining strength, lightness, and economy. Their section depends upon the nature and uses of the building, and in all cases, before they are fixed, they are proved, under a pressure exceeding the greatest load that can ever be brought upon them; care being taken, that this proof is within the elastic limit of the material. This precaution may, perhaps, be considered unnecessary with the use of wrought iron, more especially as by the mode of construction, the whole of the iron-work is tied together. It is however more satisfactory to prove the joists, and it is done by means of a lever, at a very trifling cost. The strips, which answer the double purpose of a foundation for the concrete, while in a wet state, and of a key for the ceiling, may be made of any non-combustible material instead of wood; but it will be seen, that these strips are so placed, that their ignition is impossible, as they are completely imbedded in the mortar, and have a superincumbent mass of concrete over them, which prevents the access of any current of air, and renders them practically proof against fire; this has been proved on several occasions. Amongst other substitutes for these wood strips, small clay draining pipes may be mentioned, and if made of a triangular form, they give an excellent key for the ceiling. The concrete is formed of the materials most readily obtained in the locality of the building, such as fine gravel, or ballast, burnt clay, or broken brick, mixed with a proper proportion of good stone-lime, the whole being laid on moist and well trodden in. For the finished surface of the floor, besides the ordinary flooring-boards, cements of different kinds, such as Portland, Keene's, Parian, and plaster of Paris,

may be used. Asphalte, metallic lava, slab slates, and tiles in cement, have also been employed, as a finished surface both for floors and roofs.

In applying the system to dwelling-houses and similar buildings, the joists are first tested singly, to bear weights equal to from 120 lbs. to 150 lbs. per square foot of floor; that test being, in the case of the employment of cast iron, one-third of the breaking weight; and in the case of wrought, or rolled iron, within the elastic limit of the metal. For buildings of a different character, and requiring stronger floors, the strength and the test are increased, so as to meet the requirements of the structure. The joists are then fixed on the walls, and when built upon, they form a series of ties which greatly strengthen the building. A considerable accession of strength is given to the joists, by their ends being thus firmly fixed in the walls: and every successive step in the process tends both to develop additional strength, and also to protect the joists from the effect of impact, or concussion. The strips, or pipes, form the groundwork of a continuous strut, which is completed by the subsequent application of the mortar and concrete: the latter completely imbedding the whole of the iron work, which is pressed equally on both sides, as the concrete is well trodden under the upper flanges of the joists. Thus it will be seen, that the force of compression acts upon the joists, only through the medium of the concrete, and this material is well known to be one of the best for resisting that force. The extent of addition, to the original strength of the joists, by firmly fixing the ends, and then by the perfect union and combination, obtained in the process of construction, has not been ascertained; but an idea of the enormous weight that would be required to break down a floor may be thus obtained.

Supposing the room to be 18 feet square, and to contain 324 square feet in area. The joists having an original working strength of 120 lbs. to 150 lbs. per square foot, the average ultimate strength is 405 lbs. per foot, and if it be assumed, that an increase of 25 per cent. only, is obtained by the fixing, and the consolidation of the entire mass, the breaking weight is 500 lbs. per square foot, which, multiplied by 324, the number of

square feet, gives 1446 cwt., or upwards of 72 tons, as the load required to break down the floor of a room 18 feet square; and this, it should be remembered, is not a floor in which extra strength is provided, but merely a room in an ordinary dwelling-house; which, if packed with two hundred people, or as full as the Black Hole at Calcutta, would only be loaded with 15 tons, or about one-fifth of the breaking weight of the floor. A familiar illustration of the breaking weight would be, a pile of bricks 5 feet high, covering the entire area of the floor.

In assuming 25 per cent., as the gain in strength, a low estimate is taken, for an increase of twice this, or 50 per cent., is commonly reckoned as due to the firmly fixing of a beam alone, while the great principle of this system is the gradual development of strength and firmness; the effect of the load being transferred, through the medium of the concrete, to the walls, or other vertical supports; the entire floor becoming, in effect, one solid slab, or beam, with iron ribs.

There is a limit to which single joists can be carried, on this system; but as rooms 24 feet in width have been constructed with them, and without the use of main girders, it is very rarely that the latter are required, for dwelling-houses and buildings of that class. When, however, the span much exceeds 20 feet, the adoption of girders, with joists bearing upon their flanges, is the most economical method; rooms of 60 feet span have been thus constructed, the girders having an intermediate bearing on columns placed 20 feet apart. Rooms of 30 feet, 36 feet, and 42 feet span, have also been constructed with girders and joists, without the aid of columns. It may be said, therefore, that there is scarcely a limit to the application of the system, as regards the space to be covered; while there is, probably, no kind of building to which it is not capable of being adapted. Besides public buildings of different kinds,—such as hospitals, lunatic-asylums, and workhouses; buildings for records, railway offices, banks, hotels, exhibition-rooms, baths and washhouses, training institutions, schools, &c.;—the system has been extensively adopted in private buildings, such as mansions and dwelling-houses, offices and chambers, and dwellings for the working-classes.[1] It has

[1] It is stated in "The Ninth Report of the Directors of the Metropolitan

also been employed in the construction of warehouses and mills.

It is not, therefore, merely as a theory, that this system is brought to the notice of the members of the Institution, but as a plan of construction which has been very extensively applied, and has stood the test of long experience. Whatever merit, or originality, this mode of construction may possess, is due to a recently-deceased and highly-respected member of one of the learned professions; the plan having been originally matured and successfully employed in the construction of a large private lunatic-asylum, in Gloucestershire, by the late Dr. Henry Hawes Fox. That building was erected nineteen years ago, and is as perfect at this day, as when first finished. The system was subsequently patented by him, as the only means of making its advantages known, and of bringing it into general use: and the Author's connexion with it is, as the present proprietor of the inventor's rights, and as having adapted the system to the great variety of buildings in which it has been employed.

Fig. 3.

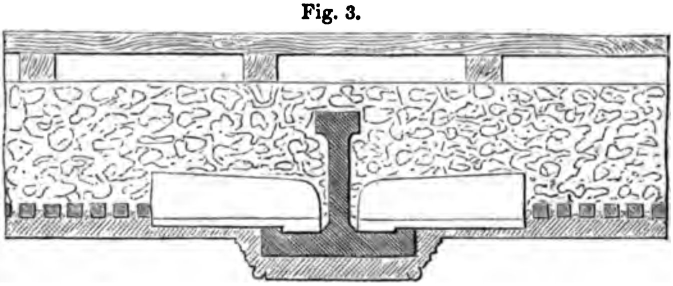


Fig. 3 is a section illustrating the application of the system

---

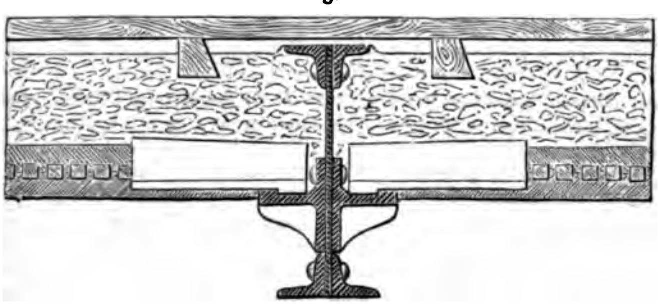
Association for improving the Dwellings of the Industrious Classes," that in the family dwellings in Mile End New Town, erected upon this principle, and providing accommodation for sixty families, not a single death had occurred in the course of the preceding year, out of an average population of three hundred; a circumstance which may be presumed to indicate, that the system is not without its advantages as regards the health and comfort of the occupants of the building. The average rate of mortality in London, in the same year, a little exceeded 22 in 1000. Besides the fact of the building being fire-proof, the Association has found that, on certain other points, this system of construction possesses advantages which are of much importance in buildings of this character; it being "very instrumental in preventing the travelling of sound from floor to floor, of vermin, of offensive smells, and of the filtration of water, in case of accident, from the overflowing of cisterns or otherwise."

with both girders and joists of cast iron, and shows the method of construction employed at a large flax mill in Ireland,—in an ironmongery warehouse at Bristol,—at St. Mark's College, Chelsea, and in various other public and private buildings, where extended bearings were indispensable. The girders, shown in section, bear either upon columns, or walls, and the joists, which are shown in elevation, run at right angles to the girders, and are cast with a shoulder, to drop over the flange of the girder, and thus to form a tie. The depth of the girders is adapted to the span, and when this depth is greater than the thickness of the floor, an intermediate flange, supported by side feathers, is cast upon the girder. The projection below the ceiling line should be covered either with plaster, or with fire-proof cement, and may take the form of a moulded beam, as shown in the figure.

The thickness of the floor, in this construction, rarely exceeds 10 inches, or 11 inches, and the saving of space, as compared with the iron-girder and brick-arch system, will be understood from the fact, that a depth of 20 inches is required at the springing line of the arches. This difference, in a mill, or warehouse several stories in height, will either economise 3 feet, or 4 feet of walling, all round the building, or will give an increased height in the different floors.

The next example (Figs. 4 and 5) shows the combination of wrought-iron boiler-plate girders and cast-iron joists, as adopted

Fig. 4.



at the recently-erected extensive additions to Guy's Hospital, where the rooms are from 21 feet to 30 feet wide. The main girders have cast brackets riveted to the web, to receive the

joists, which are cast with shouldered ends, to drop into the brackets. Considerably more than an acre of floor has already been constructed, in that building, upon this principle.

Fig. 5.

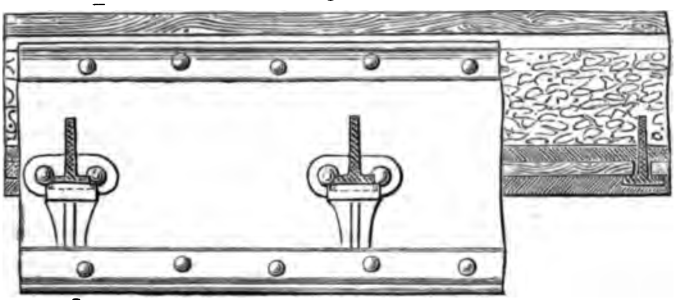


Fig. 6.

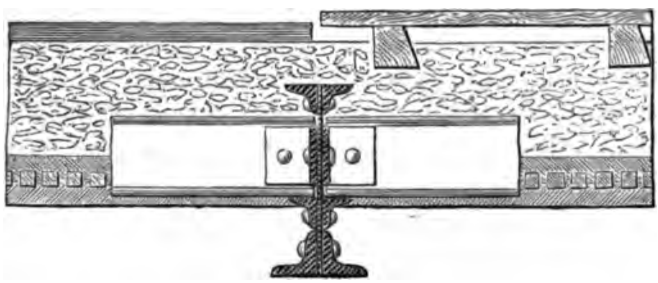
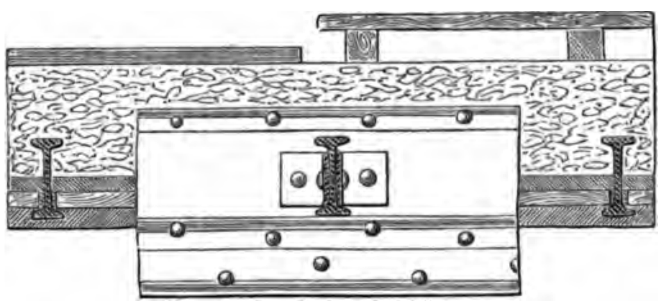


Fig. 7.

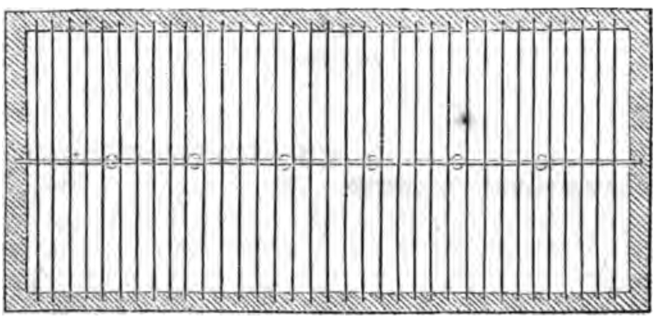


Figs. 6 and 7 show the application of wrought iron, exclusively; both girders and joists being of that material. The girders, which are of boiler-plate, have an additional, or

intermediate flange of angle iron, to give the requisite bearing for the joists; which latter are of rolled iron, and are occasionally tied to the girders by small angle plates, bolted, or riveted on them. This application of the principle has been adopted in various public buildings, 42 feet being the extreme width of bearing to which it has been at present carried; but there is no difficulty in extending it much beyond this limit, as the adaptation of boiler-plate girders to this system of construction, combined with joists of rolled iron, provides for every possible contingency, whether as regards width of bearing, the strength of the floors, or the liability to impact, or vibration.[1] In cases, however, where the use of columns can be admitted, to shorten the bearings to 9 feet, or 10 feet, the same advantages may be secured, by the adoption of rolled iron, for both girders and joists; thus avoiding the use of riveted plate and angle iron girders, the labour on which, necessarily, renders them somewhat expensive. This double application of rolled iron combines so many advantages, that it must eventually be adopted in the construction of mills, manufactories, and similar buildings.

Fig. 8 shows the plan of a floor, 63 feet by 28 feet, con-

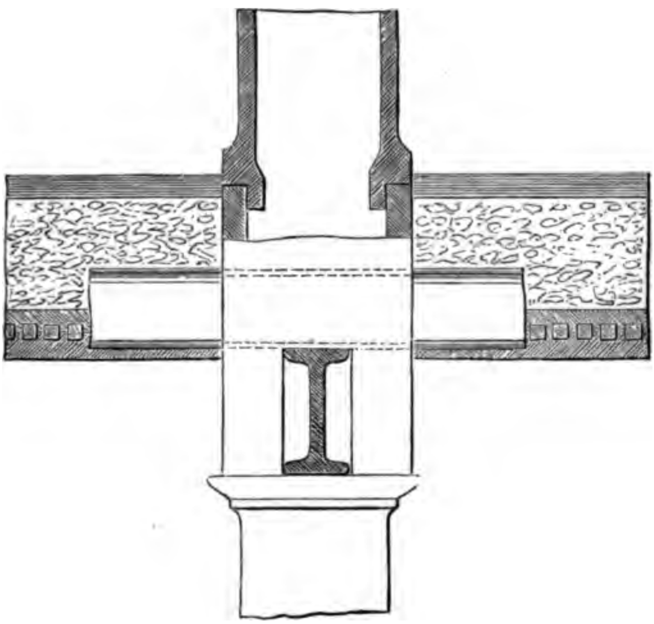
Fig. 8.



[1] The absence of vibration, in the floors of buildings containing machinery, is a point of much importance, as it not only causes loss of power, but greatly increases the wear and tear. Of some floors constructed on the fire-proof principle, at the Royal Porcelain Works, Worcester, the Architect writes:—"On one of the upper floors are three pug-mills, averaging 9 feet 6 inches in diameter, each weighing about 5 tons, and filled for 12 inches high with water, and the clays, flints, &c. used in the manufacture of porcelain. The whole masses are in motion from morning till night, without causing the

structed on this principle, with both girders and joists of rolled iron, and with a row of cast-iron columns down the centre of the room, supporting a line of rolled-iron girders, which pass through a hole in the top of the column, as in Fig. 9.

Fig. 9.



The joists are carried over the backs of the girders, and are rolled of a length to span the full width of the building, including the bearing on each of the side-walls. It is an important advantage (peculiar to the use of wrought iron), to have the joists rolled in long lengths, and fixed with an intermediate support on the main girders, as an efficient tie is thus given to the building, and the strength of the floor is greatly increased. The ends of the joists are either pierced and secured to the

slightest vibration in the floors; whilst in the Staffordshire potteries, where the floors are formed with cast-iron girders and brick arches, and nearly double the thickness, with the same works going on, the vibration is so great as to impart a disagreeable tremor to the voice of any one speaking, while standing upon them."

walls by a rod, or S piece, or they may be bolted to a plate of iron built into the wall. The extreme ends of the girders being also secured to the wall, a tie in each direction is given, and the whole forms a framework of wrought iron, possessing immense strength, each part affording efficient aid to the rest. In buildings of great width, the additional rows of columns would enable the same arrangement to be adopted; the joists being, in that case, rolled in long and short lengths, placed alternately, so as to break joint, and bolted, or riveted together, at the points where they take a bearing on the girders.

Many trials have been made of the transverse strength of the rolled-iron joists, with the object of ascertaining to what extent they may be loaded, without affecting their elasticity; and, comparing the results obtained, with the strength of similar joists of cast iron, and taking 450 lbs. on the centre, as the breaking weight of an inch-square bar of the latter material 4 feet 6 inches long, and assuming, for the sake of comparison, that the wrought, or rolled iron may be safely loaded to its elastic limit, and the cast iron to one-third of its breaking weight, the relative strength of the rolled, and of the cast iron, of the same section, would be in round numbers, as $2\frac{1}{2}$ to 1.

These experiments have, however, been carried, in some cases, much beyond the elastic limit of the iron, and it has been found, that an increase of the load, or strain, of 25 to 60 per cent., has caused a permanent set of only $\frac{1}{16}$ to $\frac{3}{40}$ of an inch, in a length of joist of 16 feet, between the points of support. These results serve to show how little the elasticity is injured, by a load far exceeding that which is practically applied.

It will be seen, that the great object, in this system, is to have the building so constructed as, in the event of fire, to confine it to the locality where it originates; an object of great importance in all cases, but particularly in mills and buildings of that description, where fires not unfrequently happen, from causes which the utmost care will scarcely prevent. That fires should extend, in these buildings, with such extraordinary rapidity is quite intelligible, when it is considered, that the floors themselves afford the fuel, and that they are so constructed as, by an unlimited supply of air, to aid, rather than to

arrest, the work of destruction; and that they are moreover not unfrequently completely saturated with oil.[1]

The question of cost is of much importance in connexion with this system of construction: with every desire, however, to place this point in its true light, yet, differing as estimates for buildings general do, it is far more difficult than would at first appear, to state absolutely, either the actual, or the relative expense. In instituting a comparison, something will necessarily depend upon locality; the relative prices of timber and iron varying considerably in different places. Much will also depend upon the nature of the finished surface adopted, and on the kind of timber floor with which the comparison is made. Instances have occurred, in which the adoption of the system having been made to turn wholly on the question of cost, the contractor has given the proprietor the option, either of employing timber construction of the commonest kind, or the fire-proof principle, with a surface of cement, or gypsum, at the same expense in either case. There can be little doubt, that in the cases, where a surface of Portland cement is adopted, the fire-proof construction can generally be executed at about the same cost as well-constructed and substantial timber-floors; but when a surface of flooring-boards is required to be laid upon the fire-proof foundation, some additional cost may attend the adop-

---

[1] The practical value of concrete, in resisting the effects of intense heat, in a building on fire, was shown at the destruction of Alderman Humphery's premises, near London-bridge, in 1851. The following is extracted from "The Times" report of Feb. 20:—"As floor after floor gave way, dropping their blazing contents into the stories below, the volume of flame increased. The immense mass of burning material gradually sank, until it rested upon the ceiling of the ground-floor. It now became a matter of surprise, that this floor, which contained very large stores of provisions, such as butter, cheese, bacon, &c., did not ignite. The arrival of Alderman Humphery solved the problem. He explained, that after the disastrous fire, by which Fenning's wharf and the adjacent premises were destroyed, he had determined to render the basement story fire-proof. Accordingly he had formed the ceiling of the basement floor of a thick layer of concrete." "The engines continued to play upon the enormous mass of burning material, which lay piled to a considerable height above the basement, and the weight and heat of which rendered it very doubtful how long the concrete flooring would withstand the severe test to which it was put. Fortunately the fear proved groundless, and during the whole of the day no appearance of any increase of the mischief was manifested."

tion of the principle, so long as the present exceptional high price of iron continues. The difference, however, is trifling, when compared with the many advantages thus secured.

An example, affording a close approximation, is given at page 263, of the comparative cost of a floor for a room of average size, in a dwelling-house, whether constructed of timber, or on the fire-proof principle, the calculations being based upon average prices; and it will be seen, that the differences are very inconsiderable. In order to establish an accurate comparison of cost, the details of the prices, which are there given, should be compared with those of any particular locality, and be corrected accordingly. The estimated comparative cost of the floor of a mill, or factory, whether constructed with timber,—with wrought-iron girders and joists, concrete, &c.,—or with cast-iron girders and brick arches,—is also given. For the floors of warehouses, no general statement can be given, as the cost will vary with the required degree of strength, and other circumstances. The same remark will also apply to the cost of floors, where the bearings are such as to require the use of main girders and minor joists; the expense depending greatly upon the distances between the girders, which the requirements of the building may render necessary.

The cost of roofs differs little from that of floors, and is governed very much by the nature of the external, or finishing surface adopted.

The introduction of any new process, in the ordinary arts of life, is always attended with difficulty, and often meets with great opposition; and any departure from a mode of construction in general use, and which has been sanctioned by so many successive generations, must necessarily be a work of considerable time. The prejudices of some and the doubts of others have to be removed; and the opposition of parties interested in resisting any change has frequently to be encountered: to which, perhaps, may be added the excess of caution, which induces a certain degree of suspicion of the soundness of the theories propounded. Hence the mere substitution of hoop-iron for the timber bond, almostly universally employed, until

a very recent period, was regarded with a considerable degree of distrust and suspicion, and for years after the introduction of this material, its adoption was opposed by those whose prejudices, or interests, were stronger than their desire for improvement. If, however, these remarks are true, in reference to a minor alteration, such as that just referred to, it might readily be supposed, that they would apply, with much greater force, to so radical a change as the one now submitted to the Institution. The advantages, however, of the substitution of hoop-iron for timber bond are now universally acknowledged,—and thus it is with almost every real improvement,—its progress, though slow, is steady and certain, and, like truth, it will ultimately prevail.

The desirableness of fire-proof construction will not, it is presumed, be denied; the simple fact of nearly half a million sterling being annually paid, in London alone, for fire-insurance, exclusive of the duty, placing this point in the strongest light, merely as a commercial question. Upwards of one thousand fires now occur annually in the metropolis, and the official inquiries as to the supposed causes of these fires show, that more than one-half of those which reach the structure of a building are considered to have originated in defective, or overheated chimney-flues and stoves, acting upon the timbers; it is therefore manifest, that the substitution of iron for timber joists would have prevented many of these fires. There is reason to fear that some of them are the work of the incendiary; and while the general adoption of a system of fire-proof construction would prove a remedy for a fruitful source of crime, there is no doubt that Insurance Companies themselves would ultimately be considerable gainers.

It is, however, important, that any system of fire-proof construction, claiming universal applicability, should, besides being free from those objections which have been referred to, as applying to timber, be also simple and economical; and these points, it is hoped, have been rendered apparent as belonging to the system described.

Although in the course of these remarks reference has necessarily been made, and an objection stated, to the iron-girder and

brick-arch system, yet it is rather to bring fire-proof construction within the reach of every one, than to offer it in opposition to other systems, or methods, that the present plan has been introduced. Hitherto fire-proof construction has seldom been thought of for general purposes; it has been generally considered that, however desirable, it was too costly for its use to be entertained; a difficulty for which a remedy has certainly now been provided, and one the value of which is not merely theoretical, but has been practically demonstrated for many years.

Of the value and importance of iron as a material for construction, perhaps too much could scarcely be said, and its comparatively limited use may probably be owing, in some degree, to the mistrust entertained as to its strength and capabilities. Objections are entertained to the use of cast iron; but however well founded these may be, they are removed by the introduction of wrought iron, in the form of joists and girders for building purposes. With the latter material it may be truly said, that every imaginable difficulty is met; and it is not one of the least recommendations of the system, that its general adoption would greatly extend the use of a material, the whole of the cost of the production of which is spent in employing home labour, and one, also, which contributes so much to the greatness of this country.

The paper is illustrated by a series of diagrams, from which the woodcuts (Figs. 1 to 9, presented by the Author,) have been compiled.

APPENDIX.

ESTIMATES OF COST, BASED ON LONDON PRICES.

Approximate Cost of Floors for Dwelling-houses.

Room 18 feet long by 16 feet wide.

	£	s.	d.		Per square.
Timber floor, of the commonest description:—					
16 joists, 17 ft. 6 in. long, 10 in. × 2½ in. = 48½ cubic ft., at 2*s*. 10*d*.	6	17	5		
Herring-bone strutting, 1 tier	0	5	0		
Wall-plate, 36 ft., 4½ in. × 3 in. = 3½ cubic ft., at 2*s*. 6*d*.	0	8	9		
½ brick trimmer and centering	0	10	0		
Outer hearth-stone, 4 ft. 6 in. × 1 ft. 6 in., at 1*s*.	0	6	9		
288 feet super. 1-inch flooring boards, at 33*s*. per square	4	15	0		
32 yards lath-and-plaster ceiling, at 1*s*. 4*d*.	2	2	8		
	15	5	7	=	£5 6 0
Timber floor, of a superior description:—					
16 joists, 17 ft. 6 in. long, 11 in. × 2½ in. = 53½ cubic ft., at 2*s*. 10*d*.	7	11	7		
Herring-bone strutting, 2 tiers	0	10	0		
Wall-plate, as above	0	8	9		
½ brick trimmer and centering	0	10	0		
Outer hearth-stone	0	6	9		
288 feet 1¼-inch battens, at 40*s*. per square	5	16	0		
32 yards lath-and-plaster ceiling, at 1*s*. 6*d*.	2	8	0		
288 feet super. sound boarding, fillets and pugging, at 20*s*. per square	2	18	0		
	20	9	1	=	7 2 0
Fire-proof floor, with Cement surface:—					
Rolled iron joists, 14 cwts. 3 qrs. 2 lbs., at 12*s*. 6*d*. per cwt.	9	4	7		
Strips, concrete, ceiling, and Portland cement surface, at 55*s*. per square	7	18	5		
	17	3	0	=	5 19 0
Fire-proof floor with 1-inch flooring boards, 23*s*. extra				=	7 2 0
Ditto, with 1¼-inch battens, 30*s*. extra				=	7 9 0

ESTIMATED COST OF THE FLOOR OF A MILL, OR FACTORY,
63 feet long by 28 feet wide.

	£.	s.	d.	Per square
Constructed with Timber Girders, Joists, and Flooring, viz.:—				
Main girder, 65 ft. 12 in. × 10 in. = 54 cubic ft., at 2*s*. 6*d*.	6	15	0	
50 joists, 29 ft. 11 in. × 3 in. = 332 cubic ft., at 2*s*. 9*d*.	45	13	0	
Wall-plate, 126 ft. run, 5 in. × 3 in. = 13 cubic ft., at 2*s*. 6*d*.	2	12	6	
Strong herring-bone strutting, 196 ft. run, at 6*d*.	4	18	0	
2 cast-iron shoes for girders, at 10*s*. . . .	1	0	0	
1764 feet super. 1½-inch deal wrought floor, ploughed and tongued with iron, at 55*s*. per square	48	11	0	
	109	9	6	
196 yards lath-and-plaster ceiling, at 1*s*. 2*d*. .	11	8	8	
				£120 18 2
Constructed fire-proof, with Girders and Joists of Wrought or Rolled Iron, viz.:—				
Main girders, 65 ft. long, 40 lbs. per ft., = 23¼ cwt., at 14*s*.	16	5	6	
Coupling-plates, bolts, fixing and ties for ends.	3	5	0	
Rolled iron joists in 30 ft. lengths, = 98½ cwt., at 12*s*. 6*d*.	61	11	3	
Fixing and tie-bolts, or S pieces for ends. .	2	15	0	
17⅝ squares, strips, concrete, ceiling, and Portland cement surface, at 50*s*. . . .	44	3	4	
				£128 0 1
Constructed fire-proof, with Cast-iron Girders and Brick Arches, viz.:—				
12 cast girders, 15 ft. 2 in. long, = 7½ tons, at £9 per ton, proved and fixed . . .	67	10	0	
Abutment-plates against end walls for tie-rods, 14 cwt., at 9*s*.	6	6	0	
Wrought-iron tension rods, 1 in. diam. screwed, 3 cwt. 1 qr. 14 lbs., at 36*s*. . . .	6	1	6	
3 rods 164 ft. sup. reduced brickwork in cement in arches, at £14 per rod	50	9	0	
294 feet super. rough cutting to skewbacks, at 3*d*.	3	13	6	
1617 feet super. clean off and point soffit of arch, at 1*d*.	6	14	9	
12 tooled York templates, 18 inches square and 4 inches thick, with caulking holes for iron girders, at 6*s*.	3	12	0	
196 yards super. concrete, av. 5 inches thick, filled in over arches and levelled, at 1*s*. .	9	16	0	
196 yards Portland cement floor, at 1*s*. 6*d*. .	14	14	0	
16 sqr. 17 ft. centering to vault, at 20*s*. . .	16	3	5	
Painting girders and tie-rods twice in oil .	2	11	10	
	187	12	0	

		£. s. d.	£. s. d.
Brought forward . . .		187 12 0	
Add for level ceiling to story below :—			
163 feet cube fir-framed binders and ceiling joists, at 2*s.* 9*d.* .	£22 8 3		
56 hoop-iron suspension straps from arch, at 9*d.*	2 2 0		
196 yards lath-and-plaster ceiling, at 1*s.* 2*d.*	11 8 8		
	35 18 11		
Deduct cleaning off and pointing soffit of arch . . .	6 14 9		
		29 4 2	
			£216 16 2

Mr. BRAIDWOOD, in answer to questions from the President, said the system described appeared to be a decided improvement on that of brick arches and iron girders, with timber floors. He objected to iron columns in warehouses: in case of fire, the draught of air and flame either speedily melted them, or so heated them, that they crumbled beneath the superincumbent mass, or else they were split by the water from the engines falling upon them. Under any circumstances they were fertile sources of danger to the firemen, as it was not possible to calculate upon the time they might resist the fire; whereas good solid timber posts endured for a long time, and the men being able to reckon something like their term of duration, felt more confidence in going into the blazing building. The water thrown on a timber support, if it had any effect at all, did good; whereas it generally accelerated the destruction of iron, or stone columns.

The great objection to wood floors, in dwelling-houses, was the facility they afforded for the fire travelling between them and the ceilings: this was obviated by Mr. Barrett's system, and it would thus tend to a greater amount of security, if it was more generally adopted. The number of detached rooms in dwelling-houses was always in their favour, especially if the floors were 'pugged.' Warehouses should, for safety from fire, be always divided into numerous compartments, communicating only through double wrought-iron doors.

Lieutenant JACKSON, R. N., suggested the use of Sir W. Burnett's system of saturating timber with chloride of zinc, which had the effect of rendering even fine fabrics of linen, or of lace, uninflammable. If this was adopted for the supports and floors of warehouses, their duration as well as resistance to flame would, at any rate, be increased at a trifling expense. The coverings of the steam boilers in H. M. Navy were ordered to be so prepared.

Mr. C. MAY did not think that any preparation would enable timber to resist, permanently, the action of flame, although the duration of the wood might be increased, which would be to some extent advantageous. In all the extensive fires he had seen, the iron columns appeared to have been melted with extraordinary

rapidity; but they became insecure long before they were melted; as at a certain stage of heating, cast iron crumbled to pieces. He thought that in warehouses the iron columns might be coated, for a thickness of 4 inches, by moulded bricks, set in cement, lock jointed, or with hoop rings; this precaution would, he believed, guarantee the columns from destruction, and be effective in keeping up the floors, particularly if they were constructed on the principle which had been described. He thought that precautions should be adopted against the effects of the expansion and contraction of so much iron, as these floors would contain, especially as, he conceived, it was meant to build the ends fast into the walls.

Mr. I'Anson said he was trying this system in a house containing an area of about thirteen squares, with three stories above the ground-floor, and nearly 50 feet high; he employed wrought-iron joists, and when painted on the underside, he had no fear of the oxidation injuring the ceilings. The rigidity of the floors was remarkable, and he thought the system could be extended to the stairs, partitions, &c., with good effect. His only doubts were, whether it was not necessary to increase the usual thickness of the walls used in dwelling-houses, as he apprehended the weight would be considerably greater than timber floors; and also as to the advantages of the use of the system for roofs.

Mr. Barrett, in answer to questions, explained, that the fusing of the cast-iron columns was occasioned by the unlimited supply of air, afforded by the ordinary timber construction, which occasioned a fierce draught like that of a melting furnace. One of the great features of the new system was preventing the possibility of such access of air to feed a fire.

The extra weight of this kind of floor was so insignificant as not to require thicker walls; the weight rarely exceeded 10 cwts. to 12 cwts. per foot-run of the walls.

It was not necessary that the joists should be painted, as the ceiling was worked upon the 'pricking-up coat' of plaster, and little, or no oxidation of the metal would take place; or if it did, it would not traverse the ceiling.

The comparative weights of various floors were about:—

Wood floor	. 35 lbs. to 40 lbs.	per square foot.
Barrett's floor	. 78 ,,	,,
4½-inch brick arch	. 70 ,,	,,
9-inch ditto	. 120 ,,	,,

Mr. Penrose suggested, whether the question of the variations of length due to the expansion and contraction of the iron, merited consideration. Iron raised from the freezing-point to the temperature of boiling water, would, in a building 80 feet in length, expand about $\frac{3}{4}$ inch. Under the changes of temperature usually observed in this country, the alteration of length would not exceed $\frac{1}{4}$ inch, which would be unimportant, except that an ornamental ceiling might possibly crack by that change.

It had been stated, elsewhere, that the shrinking of timber had torn away piers from walls. Mr. Penrose thought it could not have arisen from contraction endwise of the fibre. In his measurements at Athens, the wooden rods he used were alternately very wet and very dry, and their extreme variation was $\frac{1}{4000}$th of their length.

Mr. Barrett explained, that as the expansion of iron from the freezing to the boiling point was about $\frac{1}{800}$th of its length, and as an ordinary room rarely varied more than 20° Fahrenheit, from the mean temperature, the expansion would not exceed ·03 inch in a length of 20 feet, even if the iron was freely exposed to the heat of the room, which, however, was not the case, as it was imbedded in mortar, which was an excellent non-conducting material; therefore he thought the effect of expansion and contraction might, practically, be disregarded in this climate.

Mr. Edington said he had constructed the iron-work for the mill at Newry, mentioned in the paper; Mr. Richardson, the owner, had been determined, in the adoption of the system, not only by the apparent security it offered, but also by the absolute economy it effected, as compared with the usual construction of cast-iron girders and brick arches. If a thickness of 10 inches was gained in the depth of each floor, and the mill was five stories high, there was an economy of 50 inches of vertical

walling all round the mill. This would more than counterbalance any extra outlay on account of the weight of the floors.

The iron-work being completely buried in the concrete filling, was effectually preserved from being affected by any change of temperature, by oxidation, and even by the action of fire, to which the ordinary cast-iron girders and brick arches were imminently exposed.

The safest construction for warehouses was to have the walls of brick,—to divide the area into small divisions by walls traversing the floors,—to use Barrett's system for the floors,—to cover the whole with one, or several cisterns; and if there were any cast-iron columns, to clothe them with brickwork, and to make them act as water-pipes, with hose, &c., attached, so that the water supply might be immediately available, for extinguishing an incipient fire; this might also be done by a separate series of water-pipes in each staircase, and it would be in the power of a watchman to check a fire until the arrival of the engines. Double doors and shutters of wrought iron, with a body of air between, would materially assist in preventing the spreading of fire.

Mr. Barrett said, attention was now so much directed to fire-proof construction, that he was certain this system must obtain the suffrage of both architects and engineers, and within a few years it would be a subject of astonishment how merchants, manufacturers, and private individuals could have gone on so long, without adopting such an evidently necessary precaution, as rendering their buildings at least moderately safe from casualty.

He also pointed out one useful application of the system, which had not hitherto been noticed; he alluded to covering the reservoirs of waterworks, for which it was peculiarly adapted. It had been used for a reservoir 60 feet by 40 feet, supported by a wall 9 inches thick, and covered with turf: and had been found to be a much cheaper construction than any other that had been tried.

Mr. J. Simpson, V. P., said the covering of reservoirs for waterworks was now becoming an important consideration, as it was required by the legislature, and it was found most advan-

tageous for the consumers of water, that the light and air should be excluded, in order to prevent the germination of vegetable matter, and the generation of animalculæ. He had now under consideration the covering of nearly twenty acres of reservoirs, and as the ordinary cost was about £10 per square, any efficient system offering, at the same time, advantage in price, was important. Some reservoirs had been covered by domes, at very great cost. Groined arches of brick were objectionable, on account of the weight thrown upon the pillars, or piers, which in clay, or even in chalk, sunk and caused leaks in the reservoirs. If Barrett's system could be employed at an expense not exceeding £4. 10*s*. or £5 per square, it would be extensively used for this purpose.

The system of water columns had been tried in warehouses, at Plymouth, and a difficulty had been experienced, in preventing leaks which injured the merchandize.

The proprietor of the New Hotel, at Carlisle, in which the floors were constructed on Mr. Barrett's system, stated, that during the late heavy gales, he had been surprised to observe the firmness and rigidity of the building, even up to the highest floor; while the effect of the wind upon a mill almost close to the hotel, was sensibly felt from the roof down to the ground floor.

If floors of this construction were found to have less vibration, under much traffic, than any other kind of floors, they would be very valuable for large public rooms, which it was now the custom to place high up in the buildings, and to light from the roof; this, however, had the effect of rendering all the rooms below very noisy, when the floors were left hollow, and there was a tremulous motion, which would be overcome by this new system.

Mr. H. A. Hunt had not hitherto employed Mr. Barrett's system; he had, however, only been deterred by the fear of the extra expense it entailed on the structure; it was possible, however, that this objection might now, by greater experience, have been remedied.

He had just completed two buildings for poor-houses, at Kensington and at Westminster, and in them he had adopted,

perhaps a less perfect system, but one which he considered effective, as far as regarded preventing the spreading of fire, although it was not of such solidity as to allow it to be employed in warehouses. The plan he alluded to was simply wrought-iron girders with tile and cement arches between them, and the floor above made good with either cement, or flooring-boards, as was deemed necessary for the particular use to which the rooms were devoted. The excess of cost, in a building, the contract for which was £23,000, was £600; and in the other contract of £8000, the excess was £200; giving, in both cases, fire-proof floors.

Mr. Barrett explained, that Mr. Hunt was correct in supposing the floors could be more economically constructed now, than at the time he alluded to. He was sure that the tile-arched floor would be found more expensive and less durable than his concrete system.

Mr. Rendel, *President*, agreed with Mr. Braidwood, in the advantage of the subdivision of warehouses, wherever it was practicable, and in the use of timber pillars, in order to secure their longer duration in fires, and to give confidence to the firemen; he had for these reasons frequently employed them.

The best system of construction of floors for warehouses and factories, where first cost was comparatively of little importance, was a subject well deserving more attention than it had hitherto received; and he would suggest a paper being written, giving an account of the principal systems tried in the large warehouses and factories of the maritime and manufacturing towns.

Cast iron was evidently an objectionable material, whether used as columns, or as girders. It remained then to be shown, whether wrought iron could be advantageously adopted; and he would direct attention to the present general use of that material for girders for house construction in Paris; as also to the good effects of the filling-in between the floors and ceilings, the partitions, staircases, &c., with rubble of the oolitic building stone, bound together with plaster of Paris. A floor thus formed was sound-proof, and also prevented the spreading of fire.

The system introduced by Mr. Barrett appeared to merit the attention of both engineers and architects, as there were numerous positions to which it was admirably adapted. He hoped that the subject would be followed by a more comprehensive paper on fire-proof buildings generally.

JENNINGS' SLUICE VALVE.

After the meeting, one of Jennings' Sluice Valves was exhibited in the ante-room. The improvement was stated to consist in simplifying the construction, by casting the "body" and the "faucet" ends in one piece, thus avoiding the use of bolts, nuts, and joints. The slide was first fitted, and made to work properly in the body of the valve; it was then removed, and with two gun-metal faces, was turned, ground, and accurately fitted. The slide, through which a small hole had been previously drilled, was again placed in the valve, the two faces were introduced, and all firmly bolted together. The joints of the faces, which were dovetailed to the body, were then made with lead, or with iron cement; the bolt was removed, the hole plugged, and the valve was completed, at considerable saving of time and cost. These valves were stated to have been extensively used under considerable pressures.

February 1, 1853.

JAMES SIMPSON, Vice-President,
in the Chair.

The following candidates were balloted for, and duly elected:—Messrs. Benjamin Burleigh, John Evans, David Forbes, John Jay, Arthur Prentice, and John Trickett, as Associates.

No. 868. "On the Pneumatics of Mines." By JOSHUA RICHARDSON, M. Inst. C.E.[1]

THE necessity for good ventilation in mines is universally acknowledged, but unfortunately, very dissimilar opinions are

[1] The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

entertained, as to the quantity of air required for this purpose, and in consequence, a great diversity in practice prevails throughout Great Britain. In the Southern districts, 2,000 to 20,000 cubic feet of air per minute, and in the North, 50,000 to 170,000 cubic feet per minute, may be taken as the ordinary variations of estimates of the supply. The difference between the districts, and the discrepancy between mines, in the same district, clearly indicate the absence of any fixed principle of determining the quantity really required, and confirm the opinion expressed by the South Shields Committee, that the "ventilation, and consequent safety of the mine, is mere guess-work."[1] The customs and example of the neighbourhood, are usually the only authorities consulted on this important subject; and it is most probably owing to this circumstance, that the ventilation in whole districts presents such few exceptions to a prevailing system of good, or bad practice. There can be no doubt, however, that recourse is had to this mode, chiefly because there are no acknowledged rules to refer to, in order to obtain correct information, and it is hoped that this first attempt to supply an obvious want, will be viewed with the indulgence usually granted in such cases.

The evidence given before the Parliamentary Committees, in 1835 and 1849, and the Reports to the Government, both by able, scientific, and practical men, have elicited much valuable information on the ventilation of mines. In the admirable Report of the South Shields Committee, published in 1843, the employment of scientific instruments to ascertain the state of the mines, is strongly recommended, and amongst these, the "Eudiometer" is mentioned, as necessary "to enable the officer to discover in any part of the workings, at any time, the quantity of oxygen, and also the per-centage of Carburetted Hydrogen, or other gases." (Page 56.) This is clearly an advance in the right direction, but it does not go far enough. Dr. Hutchinson, in his evidence to the Committee of the House of Lords, in 1849, says, in answer to query 1514, "I think, that in a mine of 150 men and 30 horses, and say 180 artificial lights, there should not be less than 2,500 cubic feet of air per minute, for vital-chemical purposes alone." This

[1] Vide "The Report of the South Shields Committee on Accidents in Mines," page 56.

is equal to 16·67 cubic feet per man per minute, which agrees very nearly with the subsequent calculations. This, however, is but a small portion of the air required in a mine, and it is to be regretted that the doctor did not extend his inquiries, as they are obviously based upon true principles. In the Appendix (page 598) to the Report and evidence quoted, a paper is given, by Dr. Arnott, on the warming and ventilating of the York County Hospital, in which it is stated, that 20 cubic feet per minute of ventilating air are allowed for each patient. In the same volume (page 258) Mr. Struvé gives a formula, for determining the quantity of air required in the ventilation of mines, based on the number of men employed and the quantity of coal produced, on the presumption that 80 men work 100 tons of coal per day, giving 100 cubic feet of air per minute per man, in mines with a small amount of fire-damp,—150 cubic feet to a moderately fiery mine, and 300 cubic feet per minute, per man, in a very fiery colliery. If the quantity of the coal produced and the number of the men employed, were always in strict relation to the extent of the works, this mode of computing the quantity of air required, might possibly answer the purpose; but as the same number of men may be employed, and an equal quantity of coal produced, in a colliery of 60 acres, and in another of 600 acres, it is evident, that the ventilation, which would be amply sufficient in the one instance, would be totally inadequate in the other; for as the noxious gases are constantly oozing out of the strata, from all the exposed surfaces of a mine, the ventilation, to be efficient, must be in some relation to the areas excavated, as well as to the number of the men. Rules founded solely on the acreage, are also objectionable, as other considerations than the extent of area, are essentially necessary in arriving at a correct conclusion; Mr. T. J. Taylor[1] says,—"in a mine which yields no fire-damp, with 120, or 130 persons employed in it, I should say, that a current of 20,000 or 30,000 cubic feet per minute, might be a fair quantity; * * * but in a fiery mine, I should require very much more than the quantity named." This is equal to 166 and 230 cubic feet per minute, per man. In his Report on the Ventilation of Mines, pub-

[1] Vide Evidence Committee of the House of Lords. 1849. Query 6019.

lished in 1850, Professor Phillips says, (page 30,) when speaking of the Newcastle district,—" I have compared the quantity of air circulating in seven of these collieries,[1] with the number of men (hewers) employed; and find for every man, upon the average, 562 cubic feet of air in one minute." This far exceeds the estimates before given, and being a practical result, shows their insufficiency as guides on this subject. It is clear, that no sound basis for calculation can be founded on one, or two elements, but that the whole must be taken into consideration; for as the objects sought to be accomplished by ventilation are, chiefly, the maintenance of animal life, and the dilution of dangerous gases, it is evident, that any system which omits to recognise chemical principles, or to estimate the number of men employed,—the size of the areas,—and the length of the galleries,—or any of them, must be erroneous.

Pursuing this mode of investigation, it will be necessary, in the first place, to inquire into the chemical constitution and properties of atmospheric air, its uses in the animal economy, as well as in diluting and rendering harmless the dangerous gases; and then proceed to determine the quantity required, according to the principles adduced, and the circumstances, or conditions of the mine.

Atmospheric air is chiefly composed of oxygen and nitrogen gases, and usually contains about a thousandth part of carbonic-acid gas, with at least one per cent. of aqueous vapour. In every one hundred measures, or volumes of atmospheric air, there are 21 volumes of oxygen, and 79 of nitrogen; or in 100 parts, estimated by weight, there are 23 of the former and 77 of the latter.

Oxygen gas is the principal supporter of animal life, and combustion. It is about 750 times lighter than water, and is rather heavier than air, its specific gravity being 1·1088, that of air being one.

Nitrogen gas, or azote, as the French chemists call it, is

---

[1] The following are the mines mentioned, and the amount of ventilation in cubic feet per minute of each colliery. Hetton 190,000 C.F.; Wallsend 121,360 C.F.; Haswell 100,917 C.F.; Murton and South Hetton 87,055 C.F.; Willington 66,500 C.F.; Walker 44,800 C.F.; Castle Eden 42,326 C.F.; and Wingate Grange 44,000 C.F.—*Vide* pages 23 and 30.

Professor Phillips averages the ventilation of the above eight collieries at 196 cubic feet of air per minute to one acre.—Page 30.

(negatively) destructive to animal life, and is incapable of supporting combustion. Its specific gravity is 0·9747, and is therefore rather lighter than atmospheric air.

It appears, from careful experiments, that the proportion of these gases in the air, has been found to be the same, at the level of the sea; at an elevation of 22,000 feet; in the most crowded districts, of the most populous towns; at the summit of Mont Blanc; within the polar circle; and at the equator.

Atmospheric air is, however, undergoing constant changes, by being decomposed, and adulterated with deleterious gases. Among other causes, which are constantly operating to deteriorate the air, are the respiration of animals, and the combustion of inflammable bodies. By both these processes, the oxygen is abstracted from the air, and converted into carbonic acid, which with the nitrogen, is returned into the atmosphere. The air thus deprived of its oxygen is unfit for respiration, but in an open and unconfined space, the carbonic acid is absorbed by the vegetable creation, which retains the carbon for its own nutriment, and returns the oxygen into the air, and the nitrogen which is rejected by the lungs, being specifically lighter than air, rises into the upper regions of the atmosphere, to await new combinations; whilst the pure air descends towards the earth, to replace that which has been decomposed. It is obvious, however, that in the caverns of a mine, and even in the rooms of a dwelling-house, those natural laws are more, or less inoperative, and that unless means are employed to compensate such circumstances, disease and death must necessarily ensue among men, or animals so situated.

In order to enable the miner to pursue his avocation in the bowels of the earth with safety to his health and life, it is indispensably necessary to supply him with a sufficient quantity of pure air, not only for the purpose of respiration, but also to displace and carry away the carbonic acid, and nitrogen gases produced by it; a much larger quantity, therefore, being required for these purposes underground, than on the surface of the earth.

An example of an actual case of combustion will give an idea of the quantities entering into the calculation. A dip candle of sixteen to the pound, or one ounce in weight, was found to burn 3½ hours, which gives 125 grains of tallow con-

sumed in an hour. Supposing the tallow to contain 80 per cent of carbon, then $\frac{125 \times 80}{100}$ gives 100 grains of carbon. It requires 16 parts, by weight, of oxygen, perfectly to consume 6 parts of carbon, therefore $\frac{100 \text{ grains of carbon} \times 16}{6}$ gives 266·66 grains of oxygen, as the quantity required to maintain the combustion of the candle for one hour.

This weight must be added to that of the carbon, which makes the weight of the carbonic acid produced 366·66 grains; and as there are 812 grains of this gas in a cubic foot, the volume of it produced in an hour, by burning a candle of this description, is 0·45 cubic foot. This gas requires to be diluted with 50 times its volume of pure air to render it innocuous, therefore 0·45 × 50 gives 22·5 cubic feet of air per hour necessary for this purpose. As atmospheric air contains by weight 23 parts of oxygen, and 77 parts of nitrogen, and as a cubic foot of air weighs 527 grains[1] there is $\left(\frac{527 \times 23}{100}\right)$ 121·21 grains of oxygen, and $\left(\frac{527 \times 77}{100}\right)$ 405·79 grains of nitrogen in a cubic foot of atmospheric air; the quantity of air required, therefore, to supply the requisite oxygen is $\left(\frac{266{\cdot}66}{121{\cdot}21}\right) = 2{\cdot}20$ cubic feet; and 2·20 × 405·79 gives 892·74 grains, or (divided by 514) 1·73 cubic feet of nitrogen, as the noxious residue of the air, after the oxygen has been abstracted from it; and as it requires 20 times its volume of pure air to be mixed with this gas, to restore its vitality, therefore (1·73 × 20) = 34·60 cubic feet will be needed.

The quantity of atmospheric air required to support the combustion of a candle, one ounce in weight per hour, and to dilute and displace its noxious products in a mine, therefore is, 59·30 cubic feet, viz.:—

	Cu. ft.
For supporting combustion	2·20
For diluting the carbonic acid gas . .	22·50
For diluting the nitrogen gas. . . .	34·60

or very nearly one cubic foot per minute.

[1] The weight of all aëriform bodies given in this paper, are on the supposition that the Barometer is at 30 inches, and Fahrenheit's Thermometer at 60 degrees.

The process of respiration is, in many respects, analogous to that of combustion. The food supplies the carbon, and the oxygen is derived from the air by the act of breathing, whilst the products are the same as in combustion. In this process from ten to twelve per cent. of the oxygen in the air combines with the carbon in the blood, and produces carbonic acid, which, with the nitrogen, is expelled from the lungs, at every expiration, into the atmosphere.

Although the quantity of air which enters the lungs, at each inspiration, may be considered as uniform, yet as it is subject to great variations in weight, owing to the difference of its temperature, there is a considerable difference in the quantity of oxygen inspired in dissimilar seasons and climates.

In order to ascertain the amount of carbon taken into the human system, in a given time, and thence to deduce the quantity of oxygen required for respiration, Professor Liebeg made observations upon the average daily consumption of about 30 soldiers in barracks, from which it appears, that an adult man taking moderate exercise, consumed 13·9 ounces of carbon in 24 hours, which passed out of the system through the lungs and skin in the form of carbonic acid. The equivalent of oxygen for this quantity of carbon is $\left(\frac{13 \cdot 9 \times 16}{6}\right) = 37$ ounces; but according to Dr. Hutchinson's observations on the respiration of miners,[1] it appears they make, on an average, one-tenth more inhalations than men breathing on the surface, owing partly to the increased pressure of the atmosphere, and partly to the violent exercise they are compelled to make in working; and as the quantity of oxygen inspired is in proportion to the number of respirations in a given time, the temperature being the same, one-tenth, or 3·7 ounces, must be added to the amount given, which makes 40·7 ounces of oxygen, inspired by the miner in 24 hours, or 1·696 ounces, or 742 grains per hour.

It has been ascertained by Lavoisier and other chemists, that only 10 per cent. of the oxygen contained in atmospheric air is absorbed by animals in breathing; the other 90 per cent. being expelled by the lungs, with the carbonic acid, formed by the

---

[1] Vide "Appendix to the Report of a Committee of the House of Lords on Accidents in Mines, 1849." Page 604.

combination of the carbon, derived from the food, and the oxygen inhaled. One cubic foot of air, therefore, will only supply 52·7 grains of oxygen, and it will require $\left(\frac{742}{52 \cdot 7}\right) = 14$ cubic feet of air, to supply the oxygen needed for respiration, for one man per hour.

The air expelled from the lungs having become deteriorated, must be freely diluted with pure air, for which purpose a much larger quantity is required than for respiration. Taking the quantity of carbon consumed at 278·25 grains, there is obtained 1·256 cubic feet of carbonic acid, which should be diluted with 50 times its volume of pure air; the quantity required for this purpose is, therefore, 62·8 cubic feet per hour.

The residuary nitrogen, or azote, ought also to be diluted with 20 times its volume of pure air. In the 14 cubic feet of air, required for respiration, there is $\left(\frac{14 \times 474 \cdot 3 = 6640 \text{ grains}}{514}\right)$ 12·92 cubic feet residue of expelled air, after deducting the carbonic acid, which × by 20 gives 258·4 cubic feet of air, required for diluting this gas.

From the careful experiments of Lavoisier and Seguin it appears, that the matter thrown off by a man in perspiration, amounted to 1575 grains, or 1·94 cubic feet per hour. Although this is composed of aqueous, as well as of gaseous substances, it is so contaminating to the atmosphere of a mine, as to require a liberal dilution, and ought to be treated like carbonic acid gas, of which it contains a large proportion; the addition of 50 times its volume ought, therefore, to be allowed, which makes the quantity of pure air required for this use, 97 cubic feet per man per hour.

The quantity of atmospheric air required in a mine, for the respiration of the men, and for diluting and displacing the noxious products, is therefore,—

For breathing	14·0	cu. feet	per man	per hour
For displacing carbonic acid	62·8	„	„	„
For diluting nitrogen or azote,	258·4	„	„	„
For displacing perspiration .	97·0	„	„	„
Total	432·2	„	„	„

which is equal to 7·2 cubic feet per minute.

Air must also be provided for the horses employed in mines, the number of which is generally taken on an average as one-fifth of the number of men. According to Boussingault, a horse consumes 79·10 ounces of carbon in 24 hours, from which (calculating in the same manner as for men) it is found that the quantity of air required for the support of a horse, in a mine, is as follows:—

For breathing	80·81	cu. ft. per horse per hour.
For displacing carbonic acid .	360·50	" " "
For diluting nitrogen or azote,	1491·40	" " "
For displacing perspiration .	533·87	" " "
	2466·58	
To which should be added, for one fixed and one moveable light (59·30 × 2)	118·60	" " "
Total . . .	2585·18	" " "

which is equal to 43 cubic feet per minute.

In some instances steam power is employed instead of horses, in which case a much larger supply of air becomes necessary. If we suppose the coal thus used to contain, on an average, 70 per cent. of carbon, and that 10 lbs. in weight is consumed per hour per horse power, it will require 1086·59 cubic feet of air to supply the requisite oxygen to effect its combustion, whilst 11,050 cubic feet will be needed to displace the carbonic acid, and 17,156 cubic feet to mix with the nitrogen; the whole quantity of air required for this purpose being, therefore, for every horse-power of the engine employed 29,292 cubic feet per hour, or 472·20 cubic feet per minute. As but few steam-engines are employed underground in collieries, the quantity of air required by them is not included in the calculations and table given hereafter.

The total quantity of air required for combustion and respiration for the use of a man during one hour, with his usual accessories, must therefore be taken as follows:—

For a man's respiration, &c.	432·2	cubic feet.
For the combustion of one light, &c. .	59·3	"
For one-fifth of that needed for a horse	517·0	"
Total	1008·5	"

which is equal to 16·8 cubic feet per minute per man.

This result approximates very nearly to the estimate given by Dr. Hutchinson, which is 16·67 cubic feet per man per minute.[1]

The atmospheric air required in mines for the purposes before mentioned is inconsiderable, when compared to the quantity needed for the dilution and displacement of the noxious and dangerous gases, which exude from the strata of the earth, and which next demand attention.

These are known among miners by the names of choke-damp, fire-damp, and after-damp. In some collieries choke-damp only is found; in others, fire-damp; but both are generally present. The after-damp is the produce of explosions.[2]

The very defective state of the mining statistics of this country occasions considerable difficulty in the investigation of this subject, and in arriving at any satisfactory conclusions, as to the per-centage of these gases in the atmosphere of a mine.

It has been already stated (page 273), that in the valuable report of the South Shields Committee on accidents in mines, the use of the Eudiometer in collieries is strongly recommended. But no description of the Eudiometer, or of the mode of using it, is given in the report; and as those described in chemical works are more adapted for the laboratory than for underground observations, the Author appealed, through the columns of the "Mining Journal," to the scientific world, and was promptly responded to by the late Dr. J. Murray, of Hull, who wrote thus:—

"In my communications on coal mines, I had by no means forgotten the importance of Eudiometers. I cannot conceive anything more simple and easy, in practice, than the employment of a tube graduated into 100 parts, and fitted with a glass stopper at the summit, the lower line to commence say, two inches from the lower orifice.

"The solutions to be employed are those of Chlorine, Green Sulphate of Iron impregnated with Nitrous Gas, and Caustic Potassa, or Baryta.

[1] "I think that, for instance, in a mine of 150 men and 30 horses, and say 180 artificial lights, there should not be less than 2,500 cubic feet of air per minute, for vital-chemical purposes alone."—Evidence to the Committee of the House of Lords, 1849. Question No. 1514.

[2] The word 'damp' is probably derived from the German 'dampf,'—'vapour, steam, fume.'

"The solution of Chlorine in water, will determine the quantity of Hydro-Carbonate, or Fire-Damp present;—that of Green Sulphate of Iron, impregnated with Nitrous Gas, the relative quantity of Oxygen;—and that of Lime Water (or better, Caustic Potassa, or Baryta), the relative admixture of Carbonic Acid.

"The relative constituents of pure air are 21 per cent. oxygen, and 79 nitrogen. If on using the first test, there be several parts per-centage absorbed, this will be the relative quantity of fire-damp present.—If on using the second test, 21 per cent. is absorbed, the atmosphere may be considered relatively pure, or otherwise, in the ratio of absorption.—The absorption on employing the third test, will indicate the per-centage of choke-damp present. I consider the approximations, obtained by these means, amply sufficient for the practical purposes of the miner.

"The employment of the Eudiometer is simple: remove the stopper, and dip the tube into the solution till the liquid rises to the lower line,—replace the stopper, apply the finger firmly to the lower orifice,—shake the liquid for some time in the tube, then withdrawn from the liquid,—and finally, immerse the lower end into water, when the finger must be withdrawn, and the absorption will be immediately denoted by the rise of the fluid in the tube, and the per-centage read off. These solutions can always be kept ready for use."[1]

Choke-damp, sometimes called "stythe" and "black-damp," is composed of Carbonic Acid Gas and a greater, or less proportion of Atmospheric Air. It has been usual to consider choke and after-damp as the same thing, and in effect they are the same, both producing instant death when respired; yet, as they are derived from different sources, and recent analysis has proved, that, chemically, they are very differently constituted, it will be better to consider them separately.

Choke-damp is said to be much more prevalent in shallow, than in deep mines; it is generally abundant in old workings, and in some instances oozes out from the strata in such profusion, "that thousands of yards of space are filled with it in a single hour."[2] It is usually most prevalent in collieries generally

---

[1] Vide "The Mining Journal" of the 11th May, 1850.
[2] Vide "The South Shields Report," page 11.

free from fire-damp, owing to the sluggish ventilation which too frequently and so lamentably prevails in them. Its presence is indicated by the flame of a candle, or lamp, assuming a dull red colour, burning feebly, and finally going out. Its specific gravity being rather more than one-half greater than that of common air, it is most abundant and in the purest state near the bottom, or floor of the mine, although it is more, or less diffused throughout its whole atmosphere. Men have been known to continue their work in a mine where the atmosphere was so much charged with choke-damp, that a candle would scarcely burn, and who did not leave their work until nearly all the candles were extinguished;[1] so that they must have been in an atmosphere containing from 10 to 12 per cent. of carbonic acid, without any fatal result ensuing; yet such a practice is so replete with danger to the life, and always prejudicial to the health of the miners, as to be deserving of the strongest reprehension. At the meeting of the British Association, held at Birmingham, in 1839, Dr. G. Bird gave the details of many experiments, which he had made, in relation to this subject, whence he had, in some instances, discovered that even 2 or 3 per cent. of Carbonic Acid was fatal to animal life, and that it varied in its effect upon the human constitution, according to the different idiosyncrasies of individuals. It is obvious, therefore, that this gas ought to be diluted with at least 50 times its volume of pure air, which, though a large quantity, is not more than is required to secure the health and safety of the miners.

As the indications of the presence of choke-damp are more equivocal and less apparent than those of fire-damp, its prejudicial influence on the health of the men is probably much greater, whilst it excites less alarm; and even when the atmosphere is in a dangerous condition, it ought not to be allowed to accumulate, but should be dissipated, as quickly as it is produced, by directing and maintaining an efficient ventilation throughout all the works.

Fire-damp, known also as "wild-fire," "sulphur," and in Wales as "uldân" or "tanfa," is the most terrible enemy with

[1] Vide "Reports of the Commissioners on the Employment of Children, 1842. Mines." Part 2nd, page 739.

U 2

which the miner has to contend. It exudes from the coal, and its contiguous strata, and when mixed, in certain proportions, with atmospheric air, it acquires, on ignition, an explosive force exceeding that of gunpowder.[1] When it is recollected, that the force, or pressure of gunpowder at the moment of explosion, is, according to Dr. Gregory, about 936 tons on a square foot, the havoc and destruction, which ensues in a coal-mine, on the occurrence of an explosion of fire-damp need not excite surprise.

Fire-damp is generally composed of sub-carburetted hydrogen, and sometimes of olefiant, or sulphuretted hydrogen gases, and becomes highly explosive on being mixed with certain proportions of atmospheric air, a more plentiful addition of which however counteracts the explosive quality. Sir H. Davy, Dr. Clanny, and other chemists, have shown that it will not explode, unless mixed with from 6 to 8 parts of air to one of gas; that it requires 15 parts of air to render the gas non-explosive; and 30 parts of air to one of gas for its thorough dilution, and to deprive the atmosphere, in which it exists, of its dangerous and noxious properties.

It often happens, that fire-damp prevails in a mine to an explosive extent, and even in a still greater proportion, without an accident occurring. This arises from the mixture not being brought into immediate contact with flame, owing to the safety-lamp being used; or it may be attributed to the fire-damp not being mixed with a sufficient quantity of air, to render it explosive; or to the prevalence of carbonic acid gas, one part of which, mixed with seven parts of fire-damp, deprives it of its explosive property. A recent accident in South Wales, is to be attributed to the fire-damp prevailing in a greater proportion than rendered it explosive; the colliery being, however, in a very foul state, on a larger quantity of air than usual being forced into it, without the needful precautions, a disastrous explosion ensued, as an inevitable consequence. It is evident, that there can be no safety, where this dangerous gas is allowed to accumulate; for in such circumstances, an increased ventilation, a slight diminution of carbonic acid, or an accident to a safety-lamp, may at any moment produce the greatest danger.

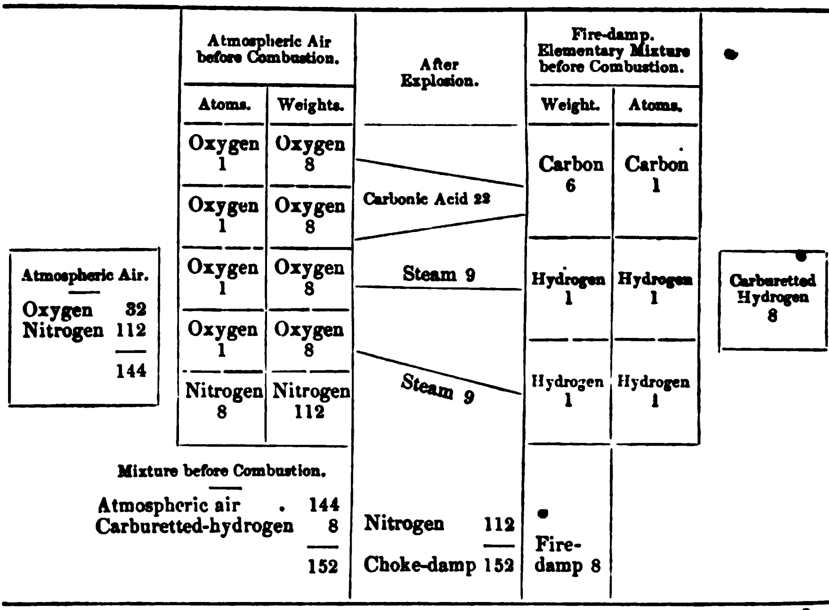
[1] Vide "South Shields Report," page 8.

It is not unusual to ascribe the occurrence of explosions to the carelessness of the men, in either not using safety-lamps, or imprudently removing the wire-gauze, whilst the fact of the gas being allowed to accumulate so as to render it dangerous, which is the primary cause, is generally overlooked. The absolute necessity for a plentiful supply of air, in all mines, will be readily conceded, when these circumstances and the poisonous nature of the gas, are duly considered; and it may be taken as established, that the health and safety of the miners, can only be secured, by diluting the fire-damp with at least 30 times its volume of pure air, and forcing it out of the mine as quickly as possible.

Sir H. Davy found, that the purest specimens of fire-damp contained $\frac{1}{15}$th of atmospheric air, and that 100 cubic inches weighed 19·5 grains, whilst the most impure contained $\frac{5}{12}$ths of atmospheric air. Fire-damp has been more recently analysed by Professor Graham, and the following are the results in two specimens, one from the Gateshead, and the other from the Killingworth Collieries, near Newcastle-upon-Tyne:—

	Gateshead.	Killingworth.	Mean.
Specific gravity	0·5802	0·6306	0·6054
Weight of 100 cubic inches .	17·70 grs.	19·23 grs.	18·46 grs.
Carburetted-hydrogen . .	94·20	82·50	
Nitrogen or azote	4·50	16·50	
Oxygen.	1·30	1·00	
	100·00	100·00	

The following chemical diagram by the late Dr. Clanny, admirably explains the phenomena of an explosion of fire-damp. Dr. Clanny devoted a great portion of his time during forty years, to this subject, and it is to his researches and experiments the miner is in a great degree indebted for the discovery of the safety-lamp; his great services and indomitable perseverance in the cause of practical science and enlightened philanthropy have, however, been but imperfectly appreciated and ill-requited.



The third column represents the equivalents of the atmospheric air in a coal mine, and the fifth shows the equivalents of fire-damp.[1]

After-damp is the gaseous product of an explosion of fire-damp, and although usually called and treated as choke-damp, is in fact a very different gas, both as regards its origin and its chemical composition,—their only resemblance being in their poisonous properties. Choke-damp is composed of carbonic acid gas and atmospheric air in various proportions; whilst according to Dr. Clanny's diagram after-damp is constituted as follows:—

$$\left.\begin{array}{lr} \text{Nitrogen or azote . . } & 73\cdot 69 \\ \text{Carbonic acid . . . . } & 14\cdot 47 \\ \text{Steam . . . . } & 11\cdot 84 \end{array}\right\} 100\cdot$$

Another important difference between these gases is to be found in their respective weights; 100 cubic inches of carbonic acid weighs 47 grains, whilst the same volume of after-damp weighs

[1] Vide "Evidence to the Committee of the House of Lords on Accidents in Mines." 1849. Page 447.

only 29·32 grains; the former, therefore, is much heavier, whilst the latter is rather lighter than atmospheric air. When choke-damp is abundant in a mine, the greatest safety may be found near the roof, but in an atmosphere of after-damp the most respirable air is found near the floor of the mine; and hence the practice, of the colliers, suggested by a dear-bought experience, of going into a mine immediately after an explosion in a stooping posture, or more generally creeping on their hands and knees.

It is a notorious fact, that in mines, although the gases may be partially diffused, yet they are usually found in a great measure stratified, according to their relative specific gravities; that is, in a mine containing choke and fire-damp, the former, which is the heaviest gas, is found near the floor,—then a stratum of common air succeeds, and the highest space near the roof is occupied by fire-damp.[1] This circumstance may probably be in fact attributed to sluggish ventilation, for if there were a brisk current of air always maintained, the gases would doubtless, be not only more diffused, but would be more speedily forced out of the mine. It is obviously of great importance, that these facts should be known, so as effectually to guard against the dangers to be encountered, as under the circumstances mentioned, it would evidently be unsafe to rely on the received theory of the diffusion of gases; for, if on the faith of it, a man were to hold a candle near the roof, in a fiery mine, an explosion would ensue, or were he to lie down on the floor, where choke-damp prevails, he would be inevitably suffocated. Nor are the consequences less calamitous, if the peculiar properties of after and choke damp are not duly regarded. Both these damps are deadly poisons, when respired; but there is usually a stratum of respirable air above the choke-damp, which enables the experienced collier to enter and work in the

[1] "It will happen at times, that men are unable to get down to work for fear of the foul air, both choke-damp and fire-damp. When examining a coal-pit, careful warning should be given not to hold the candle higher than the breast, and in that case there would be no danger (of an explosion), as the nose would give notice in sufficient time. Advice should also be given not to stoop down in any deep hole which might be seen, without holding the candle forward, in which case, if there was choke-damp, it would go out, which would be a fair warning."—Vide Dr. Mitchell's "Report on the Mines in Shropshire. Appendix to the first Report of the Children's Employment Commission." Part 1st, page 33.

mine, with comparative safety, but the after-damp occupies the whole area of the mine, immediately after an explosion, and being quite devoid of oxygen, produces instant death by suffocation, on being inhaled. On the subsidence of the violent motion of the atmosphere, caused by "the blast" of the explosion, and on the admission of pure air, the safest place is near the floor, where respirable air is soonest found.. Many valuable lives have been lost from an ignorance, or a disregard of the precautions necessary to be observed, on entering a mine, after an explosion has occurred; by men attempting to rescue their fellow-workmen, before the deadly after-damp has been sufficiently displaced by ventilation, and their attempting to traverse the galleries in an erect posture.

The after-damp is usually much more destructive to animal life, than the fire and "blast" of an explosion; the number of men that are burnt, contused, and wounded, being usually much smaller than those who are suffocated. To mitigate its dreadful effects, on the occurrence of an explosion, the most strenuous efforts ought first to be directed to the immediate restoration of the means of ventilation, if they have been deranged, prompt measures should be taken to force into the mine a greater quantity of air than ordinary, if the means of doing so has been provided by a wise and judicious foresight; should there unfortunately, be no provision of this kind, then as much air as can be spared from other parts of the mine, ought to be promptly directed to the locality of the explosion. The only efficient remedies for this great evil, are of a preventive nature, viz., a thorough and efficient ventilation, and the judicious use of the safety lamp; the best energies, of all who are interested, ought, therefore, to be directed, with steady perseverance, to perfect, as far as is possible, the systems of ventilation and the other auxiliaries to safety.

The subject which next claims attention, is the quantity of air which is required to pass through a mine in a given period, in order to maintain its atmosphere in a safe and salubrious state.

For this purpose, recourse must be had to such facts, as are easily ascertained and generally known, which may serve as foundations for approximate rules, until absolute certainty be obtained, by the use of the Eudiometer.

It must be borne in mind, that although the quantity of air required is assumed to be in proportion to the amount of damp produced, yet it is necessary to maintain a current of air through subterranean works, independent of that required for the respiration of animals and the support of combustion, for the purpose of displacing the damp and fetid atmosphere, which prevails underground, even supposing that neither choke, nor fire damp are given out from the strata. To meet this contingency, the amount of air required to dilute and disperse the choke-damp, is taken in the following estimates as the minimum amount of ventilation, required in all mines free from fire-damp. It will be necessary, therefore, first to ascertain this quantity, and then to determine that needed in fiery, and very fiery collieries.

It has been shown, that it is necessary to mix choke-damp with 50 times its volume of pure air to restore and maintain the vitality of the atmosphere. By taking the mean of the areas of the galleries and chambers of a mine, and assuming the rate of production of the gas, its volume may be ascertained, so as to approximate very nearly, to a definite rule, sufficient for practical purposes. For instance, supposing the stalls to have an area of 90 feet, the headways of 33 feet, and the air-ways of 16 feet, as in South Wales, the mean area is 46·33 square feet; according to the system of working in the Northern districts, the mean area would be from 45 to 60 feet. For the present purpose 50 square feet are taken as an average area, which may be easily modified, as circumstances may require. To ascertain, in the absence of eudiometry, the quantity of choke-damp present, there is a guide in the fact, that in mines infested with it, in certain states of the weather, candles frequently will not burn, or burn so dimly, that the men are unable to pursue their work. Now as it requires one part of carbonic acid to eight parts of common air, to destroy its power of supporting combustion, this may be taken as a measure of the choke-damp present, which is equal to 12½ per cent. To avoid exaggeration, it will be best to take only 10 per cent. as the basis of a general rule. Therefore $\frac{1\cdot0 \text{ per cent.} \times 50 \text{ feet area} =}{100}$ 5 cubic feet of choke-damp, which multiplied by 50 times its volume gives 250 cubic feet per second, or 15,000 cubic feet of air per minute. But some regard must be had to the length, as well as to the height and

breadth of the openings in a mine, as although the gases are known to ooze out of the strata most plentifully, during the miner's operations of cutting, or hewing the coal, yet it is equally certain, that it is given out, although less abundantly, in all other parts of the mine. To maintain the atmosphere of the mine in a salubrious state, the quantity of air ought to be doubled every 10 miles it has to travel, as in that distance it would gather up, in its progress, sufficient choke-damp to render it as foul as it was at first; one-tenth of the whole quantity required, ought thus to be added, for every mile the air has to course through the mine.

The air needed for respiratory purposes was estimated on the supposition, that its temperature was at 60° Fahr., which is about 10° below the usual temperature of collieries; when thus heated, the volume is dilated, and therefore contains less oxygen in a given measure, than has been determined, as necessary for the requisite purposes; the quantity must therefore be increased, in proportion to the increase of temperature. But as the barometrical pressure is increased by the depth of the pit, a correction must be made on this account. Supposing 100 men to be employed, in a mine requiring 15,000 cubic feet of air, and adding 1,680 cubic feet for respiration, the increased volume, minus that due to additional pressure, amounts to 330 cubic feet, which is equal to 3·30 cubic feet per man. To avoid complexity in the calculations, and to simplify the rules, this contingency may be provided for, by adding the amount due to expansion (3·30 cubic feet) to that required for respiration (16·80 cubic feet) and taking 20 cubic feet of air per man per minute, as the quantity required for men, horses and lights.

In mines, therfeore, free from fire-damp, and whose areas are of a mean of 50 square feet, and in which 100 men are employed, the basis for calculating the quantity of air required is:—

For diluting choke-damp, &c. .	15,000	17,000 cubic feet
For respiration and combustion .	2,000	per minute.

To this basis must be added one-tenth of its volume, for every mile the air has to course through the mine.

The following table shows the air required in a mine of 50 feet mean areas, employing from 30 to 200 men, and the air coursing different distances as stated.

Number of Men.	CUBIC FEET PER MINUTE.						
	Basis.	1 Mile.	2 Miles.	3 Miles.	4 Miles.	5 Miles.	10 Miles.
30	15,600	17,160	18,720	20,280	21,840	23,300	31,200
40	15,800	17,380	18,960	20,540	22,120	23,700	31,600
50	16,000	17,600	19,200	20,800	22,400	24,000	32,000
60	16,200	17,820	19,440	21,060	22,680	24,300	32,400
70	16,400	18,040	19,680	21,320	22,960	24,600	32,800
80	16,600	18,260	19,920	21,580	23,240	24,900	33,200
90	16,800	18,480	20,160	21,840	23,520	25,200	33,600
100	17,000	18,700	20,400	22,200	23,800	25,500	34,000
120	17,400	19,140	20,880	22,620	24,360	26,100	34,800
130	17,600	19,360	21,120	22,880	24,640	26,400	35,200
140	17,800	19,580	21,360	23,140	24,920	26,700	35,600
150	18,000	19,800	21,600	23,400	25,200	27,000	36,000
160	18,200	20,020	21,840	23,660	25,480	27,300	36,400
170	18,400	20,240	22,080	23,920	25,760	27,600	36,800
180	18,600	20,460	22,320	24,180	26,040	27,900	37,200
190	18,800	20,680	22,560	24,440	26,320	28,200	37,600
200	19,000	20,900	22,800	24,700	26,600	28,500	38,000

The universal applicability of the rule will be readily appreciated, by an inspection of the subjoined table in which the quantities required for different areas, the air coursing the distances mentioned, is shown. The air required for men, horses and lights is omitted to avoid complexity, but when practically applied, must be added to the amounts stated in the "basis" column.

Mean Areas Sq. Feet.	CUBIC FEET PER MINUTE.						
	Basis.	1 Mile.	2 Miles.	3 Miles.	4 Miles.	5 Miles.	10 Miles.
25	7,500	8,250	9,000	9,750	10,500	11,250	15,000
30	9,000	9,900	10,800	11,700	12,600	13,500	18,000
35	10,500	11,550	12,600	13,650	14,700	15,750	21,000
40	12,000	13,200	14,400	15,600	16,800	18,000	24,000
45	13,500	14,850	16,200	17,550	18,900	20,250	27,000
50	15,000	16,500	18,000	19,500	21,000	22,500	30,000
55	16,500	18,150	19,800	21,450	23,100	24,750	33,000
60	18,000	19,800	21,600	23,400	25,200	27,000	36,000
70	21,000	23,100	25,200	27,300	29,400	31,500	42,000
80	24,000	26,400	28,800	31,200	33,600	36,000	48,000
90	27,000	29,700	32,400	35,100	37,800	40,500	54,000
100	30,000	33,000	36,000	39,000	42,000	45,000	60,000

Were the per-centage of gas accurately ascertained by the eudiometer, the air required in mines would be easily and certainly known; but in the absence of such data, it would be imprudent to presume on less than 10 per cent. of gas, and even

when the quantity has been ascertained by the eudiometer to be less, the amount of oxygen in the atmosphere ought also to be tested, and sufficient air ought to be introduced, to establish and maintain the same relative proportion of vital air in the mines, as on the surface of the earth.

Fiery mines are those in which fire-damp exists, but not in large quantities; and very fiery mines, those in which it is found to such an extent, as to render the atmosphere explosive.

In the absence of better data, the measure of fire-damp in fiery mines, may be taken, at a minimum, as equal to that proportion which causes the enlargement, or elongation of the flame of a candle, or lamp, indicating the presence of one part of fire-damp to 15 parts of air, or 6·67 per cent. of fire-damp. It has been shown, that this gas ought to be diluted with 30 times its volume of pure air; then taking, as before, the mean area at 50 square feet, $\frac{50 \text{ feet area} \times 6\text{·}67 \text{ per cent.}}{100} = 3\text{·}33$ cubic feet of fire-damp which × 30 volumes gives 100 cubic feet per second, or 6,000 cubic feet per minute, as the quantity of air required to dilute this gas. But as this quantity of air is in addition to that required for dispersing the choke-damp, which is equal to 5 times the mean area, in a fiery mine the area must be multiplied by 7, to give the whole amount of pure air per second, which is required for the dilution and displacement of both these gases. In a fiery mine of 50 feet mean area the basis for calculation is (50 × 7 × 60) = 21,000 cubic feet per minute, to which must be added, the air required for respiration and combustion, and one-tenth of the whole per mile, for the length of the air-courses.[1]

In very fiery mines, in which the safety-lamp is used, the atmosphere may be fairly considered to be in an explosive state, and therefore consisting of 1 part of fire-damp to 8 parts of common air, or as containing 12½ per cent of gas. Therefore 12·5 per cent. × 0·3 = 3·75 multiplier of the mean area;

---

[1] $\frac{10 \text{ per cent} \times 50 \text{ volumes}}{100} = 5$

$\frac{6\text{·}67 \text{ per cent} \times 30 \text{ volumes}}{100} = 2 + 5 = 7$

$\frac{12\text{·}5 \text{ per cent} \times 30 \text{ volumes}}{100} = 3\text{·}75 + 5 = 8\text{·}75$

but to this, the multiplier for choke-damp, must be added, giving $(3·75 + 5·) = 87·5$ as that for very fiery mines; which in a mean area of 50 feet, as before, makes the air necessary for the dilution of gases 26,250 cubic feet as the basis for calculation.

The rules inferred from the premises of this inquiry are therefore as follows:—

In mines quite free from fire-damp, multiply the mean area by 5; in fiery mines, as described, multiply the mean area by 7; in very fiery mines, multiply the mean area by 8¾; which will give the quantity of air required for the dilution of choke and fire damp, per second, or multiplied by 60, the amount per minute. To this must be added the air needed for respiration and combustion, at the rate of 20 cubic feet per minute, per man, employed in the mine; the sum of these amounts to be the basis for calculating the increased quantity required for the distance the air has to travel, one-tenth being added for every mile, or the whole quantity doubled in ten miles. By the application of these simple rules, the quantity of air required in a mine, may be always correctly ascertained. To be safe, however, the use of the eudiometer is indispensable; if the per centage of fire-damp be greater than 12½, say for instance 15 per cent., the multiplier must be increased accordingly; for $\frac{15 \times 0·3}{100} = 4·5$ to which if 5 be added for choke-damp, makes the multiplier of the area 9½ instead of 8¾ as before.

The quantity of air shown by these rules to be requisite, may appear large when compared with the practice pursued in some districts, but when contrasted with the ventilation of some of the large and well-conducted mines in the north of England, a near approximation is apparent; for instance, the Hetton Colliery is ventilated with 198,000 cubic feet of air per minute. Taking the mean of its areas as 54 square feet, the distance the air has to travel, 70 miles, and the number of men employed as 1,000, and supposing it to be classed as a fiery mine, 172,760 cubic feet would be required by the rule, or, if it be very fiery, 212,450 cubic feet per minute.

In Haswell colliery there are 94,900 cubic feet per minute; taking the mean area at 50 feet, the air-courses 35 miles, and the number of men at 500;—by the rules, as a fiery mine, it

requires 77,000 cubic feet, and as very fiery, 95,375 cubic feet per minute.

The ventilation of Seghill is said to be 42,708 cubic feet per minute; as a fiery mine it would require 45,680; and, as very fiery, 56,600 cubic feet per minute.

Many other instances might be given, but these, it is presumed, will be deemed sufficient to demonstrate the accuracy and general applicability of the rules proposed.

The following statement of the amount of ventilation in the several collieries named, shows the great diversity of practice which prevails, and the necessity for some certain method of determining the quantity of air really required:—

	Cubic Feet per Minute.		Cubic Feet per Minute.
Derwent Main	2,000	Coxlodge	20,000
Middleton	4,445	Ardsley Main	30,957
Thorpe Hall	5,442*	Castle Eden	42,326
Tordoff, Low Moor	5,925	Felling	54,000
Holmside	8,900	Willington	66,500
Emroyd	10,408	Wearmouth	70,500
Mickley	12,856	Seaton Delaval	82,320
Eaglesbush	13,560	Haswell	94,900
West Auckland	14,478	Wallsend	121,360
West Hetton	15,300	Tyne Main	94,810
Gosforth	16,000	Murton and South Hetton	132,895
Eldon	19,179	Hetton	198,000

Thus, in twenty-four collieries, the ventilation varies from 2,000 to 198,600 cubic feet per minute; and although it is quite true that one colliery may be better ventilated with 20,000 cubic feet than another with 100,000, yet there can be no doubt, that the great discrepancy observable is more than is warranted by the peculiar circumstances of each mine, and also that it may be attributed to the non-existence of rules, by which the quantity absolutely required might be readily ascertained. The insufficiency of the ventilation, in many instances, is confirmed by an examination of the records of explosions, imperfect though they are, for it appears there have been thirty-one explosions in ten of these collieries, by which six hundred and forty-six men were killed; if, therefore, a comparison be made between the ventilation herein recommended, and that shown to be adopted in the majority of the mines mentioned, and if it be found that the amount by the proposed rules considerably exceeds that allowed in many instances, it ought not

to prejudice the theory herein advanced, but to excite reasonable doubts as to the sufficiency of the existing scale of ventilation.

It has been alleged, that the fire-damp is produced in such abundance in some collieries, that it is impossible to force a sufficient quantity of air into the mine to dilute it to a state consistent with safety. This allegation is inconsistent with recorded facts and opinions. Mr. Nicholas Wood, (M. Inst. C.E.) of Newcastle-upon-Tyne, in his evidence before the Committee of the House of Lords (1849, Query 1843), says, that 1,000 cubic feet of fire-damp per minute exceeds the quantity ordinarily produced in any mine of that district, which is the most fiery in the kingdom; therefore, the very moderate ventilation of 30,000 cubic feet of air per minute is all that is required to deprive this gas of its dangerous properties. But in addition to the gas ordinarily produced in mines, the colliery is sometimes suddenly inundated by a much larger quantity, in consequence of the workmen incidentally tapping a reservoir, or "bag of fire-damp," when the gas issues in a continuous stream by what is called "a blower," or, on the fall of the roof, it escapes in large volumes. Such casualties are fraught with great danger, and imperiously require consideration in every system of ventilation. Mr. Wood states, that the blower at Wallsend Colliery discharges 120 cubic feet of gas per minute; and Mr. Mather gives the following as the greatest quantities of fire-damp that are known to have issued from blowers:—

	Cubic feet per Minute.
In St. Hilda's Pit, in 1841, for 5 days .	1,799
In Jarrow Pit, 2nd February, 1841 .	4,000
In Percy Main, March, 1840 . .	2,618
In Wallsend, from a goaf[1] of 5 acres .	52

It is obvious that the danger arising from the sudden irruption of such large quantities of gas as even the last amount named, must be very considerably increased, when the ventilation is maintained by allowing ten, or twelve parts of air to one of fire-damp, in which state even an inconsiderable addition of gas renders the atmosphere explosive; yet this ventilation has been sanctioned by high authorities, and is, in many instances, the maximum attempted. When it is recollected, that one part

[1] This word is evidently derived from the Welsh "Ogof," a cave, or den.

of fire-damp, to eight parts of common air, makes the most explosive atmosphere, the impolicy and danger of such a system must be apparent; but if, as herein recommended, the fire-damp be mixed with thirty times its volume of air, the danger in most cases would be entirely avoided: but wherever blowers are known to exist, the per centage of gas produced by them ought to be accurately taken, and a liberal addition made to the amount of ventilation in consequence, for the quantity of the air required ought always to be calculated on a maximum scale, so as to be amply sufficient, not only for good ventilation under ordinary circumstances, but also to prevent the occurrence of an explosion by such contingencies, and to preserve the men in full bodily health and vigour.

In conclusion, it may be observed, that the results of this investigation clearly demonstrate the possibility of determining the quantity of air required in mines, by the means here proposed. The rules which have been proposed, have been deduced from the scientific principles advanced, and have been so formed as to suit the varied conditions of all mines, however different their peculiar circumstances. This has been exemplified by comparing the amount of ventilation, as required by the rules, with that maintained in three collieries of different areas and lengths of air-courses, by which it appears that the results of the theory approximate very nearly to the practice pursued in well-conducted mines. The great simplicity and easy applicability of these rules can scarcely fail, it is presumed, to be a strong recommendation for their adoption, and it must be evident, that by the substitution of principles for the mere guess-work now so prevalent, a great improvement may be rationally anticipated in the ventilation of mines, upon which the happiness, or misery, and the life, or death, of so many of the industrial population of this country mainly depend.

Mr. A. GORDON objected to the use, in these more enlightened days, of the terms choke-damp, fire-damp, and after-damp; there was now a sufficient knowledge of chemical terms to allow of a correct nomenclature being applied to the various states of the atmosphere in the mines, dependent entirely upon the more, or less prevalence of certain gases.

Mr. MACKWORTH thought the Author of the paper deserved great praise, for his persevering and disinterested efforts, to bring this subject before the attention of mining engineers, and more especially of the managers of collieries, amongst whom there was, in some parts of England, a great want of information, but on whom the lives, the health and the welfare of the colliers, materially depended. He had necessarily become acquainted with some of Mr. Richardson's views, and he could not conceive any course more desirable, than that which this Institution afforded, in the discussion and the subsequent publication of sound opinions, on the fundamental principles of subterranean ventilation.

The determination of the quantity of air to be supplied was of vital importance, whether as regarded the strength of the miner and the amount of work he performed, or his health and safety from the sudden destruction which sometimes overtook him. He was not prepared to follow the Author into the refinements of the chemical constitution, or the changes of gases, nor into the precise quantities of air required in any given mine, on account of its extent, or of the nature and amount of exuding gases and other circumstances. There was no reason, why the means for circulating a certain quantity of air should not be provided, at any mine, with the same kind of calculation, as the arrangements for pumping water; and the requirements of any colliery in work admitted of a tolerably exact calculation; but a large margin must always be allowed in the quantity of fresh air, on account of the imperfect distribution, or mixing, which could be effected, and on account of the tardy diffusion of one gas into another.

Mr. Mackworth's duties led him to consider rather the minimum quantity which was consistent with health, and he found, from extensive observations, that the least quantity of air which should be supplied to sustain vital energies alone, amounted to 100 cubic feet per man per minute. When any deleterious gases

were present this quantity should be largely increased, and when the quantity was reduced to 30 or 50 cubic feet, there was a serious diminution in the quantity of work performed by the men.

If the oxygen in the air was reduced from 21 to 18 per cent., or the carbonic acid gas was increased to 7 per cent., candles would no longer burn. But from the analysis of the air, the appearance of the surface of the coal, or the small coal in old wastes, there was evidence of a decomposition of coaly matter, which by the simultaneous action of abstracting oxygen and forming carbonic acid would render the air unfit for respiration, by the abstracting of only 2 per cent. of oxygen.

In the deep Cornish mines, on account of the high temperature, and the absence of systematic ventilation, the cost of working and of driving levels, or winzes, was greatly increased. There were cases where the temperature rose to 105°, the miners plunged into water eight, or ten times a day, the powder smoke hung on the working face, and relays of men succeeded one another every fifteen minutes. This cost might be avoided, by splitting the air and carrying it down the numerous winzes, or shafts direct to the points, where the men were at work; the various currents of air, subsequently passing through the passages, or over the 'deads' of the mine, would assume the high temperature of the rock, and uniting at the bottom of the upcast shaft, produce a rarefied column of air, sufficient to effect a considerable ventilation, and to do away with the fans, duck machines, or water-falls, which were now employed at considerable cost.

There was sometimes a misapprehension of the motive power of ventilation by rarefaction, in considering only the difference in the weight of the air in the two shafts. Since these shafts were of different depths, reached to different heights, or might be combined with a level opening from a hillside, it was necessary to take a more general definition. Motion took place in the air of a mine, by reason of the difference in the pressure in the mine, of two columns of air, reaching to the limits of the atmosphere, as might be measured by the barometer; a correction being made for the rise, or fall of the airways of the mine, according as the ascents, or descents were made by relatively cold, or warm air.

When the shafts were very distant, changes of the barometer might even operate. In the Standedge Canal tunnel, 3¼ miles

in length, a powerful current of air was to be met with, at certain times, in opposition to the wind, attributable to this cause; for the weather was sometimes quite different, on the opposite sides of the hills, through which the tunnel passed.

The water-gauge was a very rough instrument for measuring the drag of mines, and it was hardly possible to ascertain by it the whole of the drag. The proper instrument was a delicate barometer, such as the Cartesian, which by means of a second tube of smaller diameter, filled with oil, moved 6 inches to 1 inch of the ordinary mercurial barometer.

The current of air, in a mine, was like the most perfectly elastic spring, or rope, each expansion of which, by the motive power, was accurately measured by the barometer. By observing the barometer at the top of the downcast shaft, and then at the bottom, it would not be found to stand so high, in the latter case, as a calculation for the depth and temperature of the shaft would indicate. The difference was the drag of the downcast shaft. In the same manner the whole drag of the mine might be calculated, as far as the bottom of the upcast shaft.

The measurement of the drag and the power of the upcast shaft required more careful consideration. From some recent experiments, made by Mr. Nicholas Wood, at Killingworth colliery, when he placed water-gauges, at short intervals, in the brattice of the upcast shaft, it appeared that the heights of these water-gauges did not decrease in any regular order, but in a very singular curve. The curves were totally different for different ventilating powers, and tended to explain, more clearly than any other means, the mode of action of the steam-jet and its difference from the furnace.

By a number of such observations with a barometer, the total amount of drag and power might be ascertained. It was a question, involving the relation of the area to the depth of the shaft, and to show the importance of its investigation, it was only necessary to point to the discrepancy which existed between the proportions of chimneys, to obtain a certain quantity of air, given by the ordinary Boulton and Watts formula, and those of the most powerful furnace upcast shafts.

The difference of the mean temperatures of the upcast and downcast shafts, and the total drag of a colliery, each varied as the square of the ventilation. If the drag was represented by lbs.

pressure, per square foot, and multiplied by the number of cubic feet of ventilation, the product was the number of units of power expended in ventilation, and varied as the cube of the ventilation. This abstract law was exactly demonstrated by experiments with Struvé's ventilator:—

Number of Strokes per Minute.	Quantity of Air per Minute.	Drag of Colliery.	Horse-power utilised.
	Cubic Feet.	Inches of Water.	
6	8136	0·25	0·32
10	13560	0·75	1·6
15	20340	1·65	5·3

These experiments were on a single airometer, 12 feet in diameter, working on a 6-feet stroke.

When there were several splits of air in the mine, the drag did not increase exactly as the square of the ventilation, as on an increase of the power, the air became differently distributed, a larger proportion going through the split of shorter length, or larger area, or through a regulator if there happened to be one. In accurate experiments the hygrometric state of the air must be considered, as the return air being nearly constant in its dampness, any change in that respect, in the downcast shaft, altered the amount of ventilation. By keeping the ashpit of the furnace full of water, so that the evaporation partly, or nearly saturated the heated air, a considerable gain was effected in the ventilation, by the increased buoyancy of the upcast column.

Biram's anemometer, which was usually employed for measuring the velocity of air in mines, though very portable and convenient, had an error arising from friction, which varied in each instrument. None of the published tables were accurate, and it was much to be desired that each anemometer (like other meteorological instruments,) should be tested by the maker, and a correction given with it. In a recent measurement of the air in the Seaton Delaval colliery, in which great accuracy was desired, the correction had to be applied, by moving each instrument in a room in a circle of regulated radius at the same velocity as that observed in the mine. The difference between the space travelled and the velocity indicated, was the correction to be applied. Monsieur Combes, the eminent engineer, experi-

mented on his ventilator, by setting it in motion at the end of an arm moved by clockwork at regulated speeds. The corrections he found to be of the form $a \times b\,x$, where x was the number of revolutions, a and b, were constant in each instrument.

It was, perhaps, unfortunate for the proper investigation of the various ventilating powers, that an antagonism had been set up between them, by rival parties, to determine an abstract question of superiority, instead of investigating the peculiar and distinctive properties of each, and the particular circumstances under which each was most applicable, or most economical.

It would not be difficult to select collieries where any one ventilating power, now known, would suit better than the others. When the upcast shafts were used for winding, the furnace, or jets caused damage to the machinery, and the speed of the upcast air was reduced from 30 feet to 10 lineal feet per second. If the shaft was not walled, it would cost £10 per month for repairs, and four-fifths of the heat of the furnace would be sometimes lost. If the shaft was not deep, very little effect was produced by the furnace, or steam-jet; the amount of ventilation varying as the square root of the rarefied column. The steam-jet, acting only by impulsive force, was one of the most expensive ventilating powers; but still, when connected with an underground engine, it might, in some cases, be usefully employed, on account of the rarefication produced by its temperature. As an auxiliary power, capable of instantaneous application, on the occurrence of an explosion, it would be valuable at every fiery colliery, connected with the boilers of the existing engines at the surface.

The furnace being erected at a small cost, being simple in its application, and generally recognised, as a means of greatly increasing and rendering more uniform the natural ventilation, its adoption was generally recommended. The amount of its effect could only be roughly calculated beforehand; and few engineers would be bold enough to predict what effect the consumption of a certain quantity of coal would produce in any given colliery. Even if the performance of a colliery at one temperature was known, there was no formula, in general use, which would give the accurate consumption of fuel required for another amount of ventilation. Deduced from Tredgold's well-known formula, the fuel increased as the cube of the ventilation,

—according to Combes' proportions, nearly as the fourth power. It appeared, however, that the consumption of fuel increased rather more than the cube, at low temperatures in the upcast shaft, and nearly as the fourth power, at the higher temperature, *i. e.*, approaching to 150°. The loss of heat at high temperatures explained this variation.

There were many collieries which could not be ventilated, by either the furnace, or the steam-jet.

In Somersetshire, the shafts, only 4 or 5 feet in diameter, and 400 yards deep, were closed by the ascending and descending tubs, as by a valve. Extensive workings were often carried on by levels, or incline drifts, which did not admit of a rarefied upcast column of sufficient height; some seams were so thin, and the airways were so small, that the drag of the colliery exceeded any power exerted by either the furnace, or the jets. It was often desirable to make the pumping pit the upcast shaft. In other cases it might happen, as Mr. Mackworth had seen only a few days ago, that such a quantity as 60,000 cubic feet of air was required to come up a shallow shaft, of an area of only 35 square feet. In such cases mechanical ventilation must be employed. There was a prejudice in this country against mechanical ventilation, not founded on experience, and which was totally opposed to the practice in France and Belgium. Struvé's ventilator, which dipped into water, and was suspended to a beam, was less liable to fracture than a pumping engine, and the daily and weekly opportunities of repair, rendered a stoppage very improbable. No danger could arise from the stoppage, if the men were compelled to come out when the current of air ceased, which might be effected by rules and discipline. In Belgium, where every precaution in such matters was used, mechanical ventilation was largely employed, and the use of an ordinary furnace, at a fire-damp colliery, was forbidden by law. At the Middle Dyffryn colliery, on 10th of May last, sixty-five persons were killed, in consequence of an explosion at the furnace. The colliery had been worked two years, and extended over thirty acres.

After the ventilator was set to work, the air at the other end of the mine was, in 10 seconds, found to be moving at the velocity of 30 lineal feet per minute; and, in 2 minutes, the air had attained its highest velocity of 600 lineal feet per minute.

It would, therefore, be safe and effective to apply directly after an explosion, whereas a furnace was dangerous.

In South Wales there had been some of the best examples of furnace, steam-jet, and mechanical ventilation. The cost of these, including capital and repairs, for every 1000 cubic feet of air passed through the usual workings at 1¼ inch of water-gauge, had been, for the steam-jet, about £17 per annum,—for the furnace, £8 per annum,—for Struvé's ventilator, £6 per annum. The cost of the latter would be still further reduced, when, as in two late instances, it was worked by the same engine which did the winding and the pumping.

A double ventilator now erecting, with each of the airometers 20 feet in diameter, would exhaust 10,000 cubic feet of air at each stroke, and making ten strokes per minute, would possess a power equal to the ventilation of the largest colliery, except two.

The relative efficiency of several mechanical powers might be given thus:—

Useful work by the consumption of 1 lb. of coal.

Furnace	Tyne Main Colliery . .	0·88
Furnace	Cwm-bach Colliery . .	0·56
Furnace alone	Dyffryn Colliery . . .	0·50
Furnace and steam-jets .	Dyffryn Colliery . . .	0·09
Boiler-fires and steam-jets .	Seaton Delaval Colliery .	0·44
Steam-jets alone . . .	Seaton Delaval Colliery .	0·31
Common straight vane fan	Skier's Spring Colliery .	0·87
Fabry's pneumatic wheels	Belgium	2·70
Struvé's ventilator . . .	Eaglesbush Colliery . .	2·67

The work was ascertained by multiplying the resistance into the velocity of the air.

Another class of motive powers, little known in this country, were the water-blasts, used in blowing the small iron furnaces in Germany, and for ventilating mines. In one instance, by a fall of 30 feet, a pressure of 33 inches of water was obtained, and the water was forced through a pipe, 4 inches in diameter, and 450 yards in length, in order to ventilate a small mine. The apparatus consisted of a cistern, with an upright pipe under it, and below that an air-trunk, terminating in a box. The air entered by holes near the top of the trunk, and the water bringing it down, and breaking on a wooden block in the box, propelled the air along a horizontal air-trunk to the working fall. In Cornwall, a simple, but more imperfect kind of water-

blast was used, in the bottoms of deep mines, to send a small quantity of air to the ends of the drifts. Another kind, which was used to some extent, consisted of an upright pipe, 60 or 80 yards long, and 1 inch to 2 inches in diameter; the water escaped, under this great pressure, through a number of small pierced holes, radiating so as to enable the spray to fill the area of the air trunk, or small shaft. In one case, the discharge from 6 holes, $\frac{1}{16}$ inch diameter, drove the air 700 yards through a wooden trunk, 10 inches square, at the rate of 20 lineal feet per second. These water-blasts were applicable in mines, shafts, and drifts, especially when, as was usually the case, there was an excess of pumping power, or the water could be discharged through an adit. In tunnels the expense of a second drift could be saved.

The neglect of the proper distribution of the air in coal mines, was a more fertile source of accident than the deficiency of ventilation. The actual discharge of gas, in fiery mines, was small, compared with the quantity of air. There were few collieries where the velocity of the air, at all the working faces, was 3 lineal feet per second; the current generally considered necessary. The fire-damp generally clung to the roof, and the brattice should be placed sloping outwards, so as to throw the body of the air (entering by the narrow side of the brattice) up into the roof.

The natural ventilation of collieries, in the winter time, when the difference in the temperature of the upcast and of the downcast shaft was about 25°, should amount to about one-half the proper artificial ventilation. In laying out the ventilation of a colliery, the quantity of air required being determined on, the currents should be so split, and the air-ways be so enlarged, that one-half the ventilation could be obtained in winter-time by natural causes without any furnace being applied. The natural ventilation of Hetton colliery, where splitting was carried to an extreme, was 100,000 cubic feet per minute.

As to safety lamps, great ingenuity had been exhibited in devising modifications of Davy's and Stephenson's lamps, so as to produce numerous forms, by varying the positions of brass and wire gauze cylinders. Both these lamps, when in good condition, were perfectly safe. In considering the actual use of lamps in mines, one of the most important considerations seemed to be

the quality of giving early indication of the presence of fire-damp, by a halo round the flame. This halo was seen, when the quantity of fire-damp in the air was between 3½ per cent. and 7 per cent. The universal practice in collieries was, for the deputy, or fireman, to run round the working places of the colliery, before the colliers went to work. Each place was rapidly tried with this lamp, and if there was no halo, he allowed the men to work with a naked light. It might fairly be said, that in a fireman's hands, this margin of 3½ per cent.,—between safety and explosion,—between life and death,—was reduced to 2 per cent. or less. A more delicate lamp, or some rapid practical test, or "gazoscope" was much to be desired for collieries.

To prevent explosions in collieries, it was generally acknowledged that good ventilation, and the exclusive use of safety lamps were required. There were, however, very few collieries where this course was adopted, although, in several instances, where the danger was considerable, the colliers worked for the same price with the Davy lamp as with the naked light. Eloin's lamp had made some progress, and gave an excellent light.

Precautions against the after-damp (which destroyed so many lives after explosions) were generally neglected. If the shafts were not bratticed, there were doors between the bottom of the shafts, which caused the same loss of life.

The nearest approach to perfection in the ventilating arrangements of a colliery might be stated to be, its being rendered self-acting. The stoppings should be made firm,—the doors be removed from the principal roads,—and the whole work be divided into separate panels, at the upper end of which there should be an indestructible regulator, of masonry. If an explosion happened, it was confined to one panel,—the brattices and sheathings were blown down, so that the air took a short course through and passed in a larger quantity, on account of the less resistance, and sufficiently near to the men who were making their escape.

Mr. Mackworth felt that his attention had been diverted, in these remarks, by the more attractive part of the subject, from the state of the non-fiery collieries, where an amount of disease and injury to life was engendered, actually far exceeding the ravages of fire-damp. It existed, principally, in smaller mines, and those not hitherto much visited. It was found, that by

natural ventilation, in very cold weather, 100 cubic feet of air per man per minute could be introduced into any mine. This quantity was sufficient to obviate the more serious evils, and to greatly diminish the cost of working the coal. Mr. Mackworth was, of opinion, that artificial ventilation should be enforced in all collieries, and that the quantity he had mentioned should be regarded as a minimum.

Mr. J. Gibbs said the tenor of all discussions on this subject, was to urge upon miners the necessity of precaution against accidental loss of life; now he considered, that, while it was undoubtedly necessary to guard against explosions, a greater degree of attention ought to be paid to the health of the men while at work. The principle of Government inspection might, perhaps, be advantageous in this respect; he had found many colliery agents grossly ignorant, and a better system of instruction, than at present prevailed, was seriously required. The Continent afforded a good example; there they had good schools, with limited practice, while here, there was extensive practice and no schools.

The great point was to keep the mine continually full of good fresh air, in order to enable the men to work comfortably, and without endangering their health; this would be found to conduce to the profit of the coal-owner, as the longer men could work, the greater would be the quantity of coal raised in a given time and without increase of any of the dead charges of a mine, which were almost as heavy for a small as for a large quantity of coal.

The application of general theoretical rules, was always difficult, and in mining it was particularly so, as each individual pit would probably present some peculiar feature, which would modify the circumstances. The large collieries did not present the anomalies of the smaller pits, and it was probably more difficult to arrange a good system of ventilation for the latter than for the former; besides which it was not practicable to receive for them such efficient supervision as for the important collieries. He was of opinion, that the system of exhausting the air was preferable to forcing it in by mechanical means. From the experience of some years, he was not an advocate for Government inspection as at present pursued.

Mr. R. Stephenson, M.P., V.P., said, if it could be

shown, that an extended system of Government inspection would ameliorate the condition of the miner, and prevent that awful loss of life which too frequently occurred, for humanity's sake they must all support its extension. He, however, did not think, that any number of Inspectors could avert the evil; for he had known a mine perfectly healthy in the evening, but by the next morning, from a change in the atmosphere, and the exhalation of carburetted hydrogen, it had become very dangerous; no Government Inspector could be of the slightest service in such a case. There could be no objection to inspection as far as seeing that all known scientific means were adopted, and every precaution was used. He admitted with regret, that there were some cases of great carelessness and neglect, yet the majority of owners and viewers were, for their own interest, very careful. Few would knowingly risk the lives of fifty, or a hundred men, and the destruction of their own property, when a little caution, exertion, and trifling expense would guard against it. The real want was a system of education, which would prepare young men as colliery viewers, by giving them a scientific knowledge of the natural operations going on in a coal-mine, so that when danger existed they would be prepared to guard against it. He was himself a coal-owner, and he took care to appoint as his working agents, only such men as he found competent, and whom he could depend upon for care and watchfulness. They were always on the spot, and upon them the responsibility must rest. If, however, the Government inspection was extended to minutiæ of management, the resident agents would feel themselves relieved from the responsibility, and anarchy, confusion and loss of life and property must be the result.

He gave Mr. Mackworth much credit, for the general correctness of his remarks, and for the close attention he had evidently paid to the subject. There were, however, some points in which he differed with him. It was impossible for any formula to give correctly, the quantity of air necessary for a mine, having any certain number of men at work, as circumstances so continually differed. He considered it a dangerous precedent, therefore, to lay down any rule, such as 100 cubic feet per man per minute. If an empirical rule was attempted, it should be for a given number of cubic feet of air to dilute and sweep away the

deleterious gases. If no gas was generated 100 cubic feet of air would suffice; but if, as constantly occurred, there was a sudden outburst of gas, or constant, though slow exudations, that quantity of fresh air would not preserve the energy of the miners, although it might support life.

Mr. MACKWORTH explained, his meaning to be, that as a minimum, every man should be supplied with 100 cubic feet of pure air, which was sufficient to support vital energy. In whatever state a mine might be, sufficient atmospheric air must be introduced to give every man 100 cubic feet of a healthy breathing medium per minute, whilst some mines might require 500, or more cubic feet per man per minute, to dilute explosive, or other gases.

Mr. STEPHENSON resumed—Even then he could not agree to the proposition, he deprecated a dependence on any fixed rules, where conditions were so continually changing; every manager of a colliery should pay constant attention, and take every advantage of circumstances, and the best results would follow. He had also an objection to what was called "natural ventilation;" it was a new term to him, and he could not comprehend what was meant by it. Such an idea should be admitted with great caution, as it was to be apprehended, that in a colliery left to that kind of ventilation the currents would be apt to be reversed. Such accidents did occur in old-fashioned collieries, and when even anything approaching to perfect equilibrium was established between the two shafts, there would be liability to reversed currents.

The system of exhausting, was preferable to that of forcing in air, as in the former case the natural pressure came to the aid of the artificial means. Experience seemed to point still to the rarefying furnace at the bottom of the shaft as the best and most economical means of establishing and ascertaining adequate ventilation. Most probably the Dyffryn Colliery was a newly-opened mine; it was generally observed that accidents occurred more frequently in new mines, as there was a very copious supply of atmospheric air, and the most explosive mixture was in the proportion of seven parts of air to one part of gas. At the Killingworth Colliery, it was not an uncommon occurrence to see flashes of blue flame, at the furnace. It was incumbent on the mine-agents to watch every movement of the

barometer, as no other guide would be unerring, and when it indicated a fall, by increasing the intensity of the fire, the ventilation could be maintained.

Mr. Mackworth explained—he had stated, that at this season, when the atmosphere, and consequently the downcast shaft were at a low temperature, say 40°, while that at the bottom of the mine, and in the upcast, would be perhaps 65°, (particularly if the top of the latter was of greater elevation than the former,) a current would always run through the mine; this he termed "natural ventilation."

Mr. Stephenson could not agree that such a current could be depended on, and he thought it would be productive of danger; the furnace was the best method of securing a sufficient and regular current, under all the circumstances which had come under his knowledge; and although danger was sometimes apprehended, from its assumed tendency to fire the gases passing over it, it rarely happened that explosions occurred from it.

Mr. Mackworth said, that collieries in Somersetshire contained four, or five seams of coal, from 1 to 2 feet thick, and were worked over an extent of one hundred acres, from two pits of 4 feet 6 inches diameter each, without any artificial means of introducing, or of exhausting air.

Mr. Stephenson thought the plenum system might, under circumstances of small variation of atmospheric condition, present some theoretical advantages, but practically the vacuum system was more to be relied upon, as it did not depend upon the action of machinery, which should always exist in duplicate, to provide against accident and sudden emergencies.

Mr. A. Gordon stated, that it was rare to find in the Cornish mines, a man of upwards of fifty years of age; this was generally attributed, not so much to the wearing out of the muscular energy by labour, as to the debilitating effect of want of fresh air in the mines: men of forty had all the appearance of being sixty years of age.

Mr. H. Mackworth, in reply, said he might be permitted to state, that in the main he agreed with the remarks which have fallen from Mr. Stephenson and Mr. Gibbs, and he would explain how far he did agree. His statement was, that 100 cubic feet of air, per man per minute, was the minimum quantity required for supporting the vital energies, in a mine. This

remark was intended to extend to metallic mines, as well as coal mines, and this quantity was altogether independent of the gases given off by those mines. In every case the nature and quantity of those gases must be ascertained, as well as the proportions of air required, for rendering them innocuous.

With regard to the term natural ventilation, if (as had been stated) there was no such thing, then one-half of the collieries, and nearly all the other mines, in the south-western district, in some cases employing from two to three hundred men, must be entirely without ventilation. Mr. Mackworth was in the position of having a very large number of collieries to inspect, one-half of which had no artificial ventilating power, and he deeply felt the important objects which he had still to obtain, by dint of persuasion and by spreading information. He fully responded to the importance of mining schools; not only those, commonly so called, but also of that invaluable practical school which was to be found in the best Newcastle mines.

In behalf of the Government inspection, he might state, that instead of pupils going to mining masters, a course very much to be decried, the Inspectors went direct to the managers and overmen, explained the deficiencies and dangers of their own works, which they had before their eyes, gave them several hours' instruction as to the leading improvements in collieries, and, when they could read, referred them for further information to the reports of the Committees in the Houses of Lords and Commons; to which Mr. Stephenson and several eminent Engineers had given their valuable aid, It was true, that it was impossible for the Inspector to foresee all the dangers, or the contingencies that might arise; and common sense would show the manager, that all the responsibility must actually rest with him.

The existing defects in the mining system, could not be quickly remedied, but in the lapse of years it might be hoped, that great improvements in the economy and safety of mining, would result from the operation of the system of inspection which was now only in its first stage.

Mr. J. Gibbs admitted, that he was an advocate for mining schools for the education of the "overmen" who were, generally, very valuable assistants; but it must be remembered, that the mine agents in Mr. Stephenson's colliery must not be viewed as

average specimens of the class, as few persons knew so well how to select them, or treated them so liberally, or with such consideration. Such education, as had been mentioned by Mr. Mackworth, could not fail in being productive of benefit, and would do more real good than any interference, by Government inspection, in the technical working of mines.

Mr. J. SIMPSON, V.P. said it was gratifying to observe the wide range taken in the discussion; the necessity for a system of national scientific mining education had been strongly advocated, and, from the marked attention paid by the meeting, and the emphatic approbation shown at any important expression of individual opinion, it appeared certain, that this important subject was exciting more attention among engineers, generally, than had hitherto been the case, and the happiest results might be anticipated. It was evident, that science and art, though perhaps slowly, were surely at work for the discovery of the best means of conducting the practical operations of the coal mine, with the greatest amount of safety to the men, the least cost, and the largest return to the employer. Every detail connected with colliery works had been ably discussed; the amount of air necessary for thorough ventilation; the best mode of supplying it; the various chemical and mechanical means to effect that object; the several instruments which should be constantly in use; safety-lamps, and what was termed "natural ventilation," all had undergone searching and highly-interesting investigation. He wished, however, to direct special attention to the Northern Institute of Mining Engineers, recently established at Newcastle-upon-Tyne, under the presidency of Mr. Nicholas Wood, M. Inst. C.E.; as it was generally urged most strenuously, that whatever improvements might be effected by science, in colliery development, no certain dependence could be placed on any mode of operation, without a thorough system of practical mining education was established; but by affording means for the practical training of young men, as colliery viewers, they would eventually bring the resources of chemical and general scientific knowledge to the aid of watchfulness and practical skill in the mines, and there could be no doubt, that the result would be a vast decrease in the number of accidents.

February 8, 1853.

JAMES SIMPSON, Vice-President, in the Chair.

The discussion upon the Paper No. 868 "On the Pneumatics of Mines," by Mr. Joshua Richardson, having been renewed, was extended to such a length as to preclude the reading of any other communication.

February 15th, 1853.

JAMES MEADOWS RENDEL, President, in the Chair.

No. 886.—"On the Use of Heated Air as a Motive Power." By Benjamin Cheverton.[1]

The principle of employing heated air as a motive power is very old; but it appears to have been first used in a really efficient form by the Messrs. Stirling, of Scotland, in the year 1827. Messrs. Parkinson and Crosley also brought forward an air-engine in 1827, in which the arrangements were very similar to those of the Messrs. Stirling, although not so well devised for economising heat; but they introduced the principle of using air of greater density than that of the atmosphere, and so obtained an engine of greater power in the same compass. In both these projects, the same vessel became alternately the heater and the condenser, according as the air was made, by the action of a plunger, to occupy the hot, or the cold end; and thus the necessity of forcing a continual supply of cold air into the heater was avoided. But in the year 1833, Lieut. Ericsson, whilst a resident in this country, brought forward his caloric engine, in which, reverting to the steam-engine type, he made the heater and condenser distinct vessels, with permanent functions. This arrangement was necessarily accompanied with what may be termed a force pump; but which is called by the inventor the "supply cylinder." As under the temperature employed, the

---

[1] The discussion upon this Paper extended over portions of three evenings, but an abstract of the whole is given consecutively.

expansion of the injected air is only double, this force-pump becomes a formidable affair, requiring its cubic contents to be half that of the working cylinder. If the heated air were allowed to escape freely, there would be a loss of heat; it therefore occurred to the Messrs. Stirling to employ it in heating the incoming air; and it is important to notice, that this principle was acted upon by them from the first, and that the means they employed to carry it into effect consisted of metallic laminæ, and also wire gauze, through the interstices of which the hot and cold air passed alternately — the contrivance being analogous to the subsequently introduced, medical respirator of Julius Jeffreys. Ericsson brought forward the same principle; but his arrangements were somewhat different, inasmuch as his abstracters and transmitters of heat consisted of a series of tubes in pairs, the one being enclosed within the other. In 1840, Messrs. Stirling took out a second patent for improvements on their engine; but they referred only to matters of detail, and were of no great importance. In 1845, the invention was explained to the Members of this Institution, and was the subject of an interesting discussion.[1] In 1851, Lieut. Ericsson also a second time patented his caloric engine, with improvements, the principal one consisting in the adoption, in the "regenerator," of the means already employed by Messrs. Stirling, for abstracting and transferring heat from and to the hot and cold currents of air.

Though the respective engines of these gentlemen are, in their latest forms, characterised by the same principles, and essentially by the employment of the same means, yet they are widely different in their construction and arrangements, on account of one party employing a force-pump to inject air from the cold vessel to the hot one, and the other dispensing with it, by displacing the air from the cold and sending it to the hot part of the same vessel;—but in both inventions, the air, during this transfer, percolates through the interstices of a metallic mass, alternately receiving and imparting heat in its passage. Both parties also rest the efficiency of their engines on the repeated use of caloric; —they contend, that in recovering from the ejected hot air, the caloric which gave it superior tension, and employing it in heating

---

[1] Vide Minutes of Proceedings, Inst. C.E., 1845. Vol. iv., page 348.

the injected air, "it is made to operate over and over again." Mr. Ericsson aspires to embody a new principle in motive mechanics, no less, to use his own words, than "that the production of mechanical force by heat is unaccompanied by the loss of heat," except such as arises from radiation, or other practically unavoidable waste.

It is to this point, chiefly, that attention must be directed, for if this is a correct statement of the merits of the "caloric engine," it is impossible to over-estimate the importance of the invention, in comparison with which all past discoveries in motive mechanics are utterly insignificant. This new principle must be submitted to the test of general laws, and if it will not bear this scrutiny, such advantages as the new engine may possess over the steam-engine, (if such shall be proved) might be referred to circumstances of a practical nature, which it may be worth while to ascertain and discuss.

Caloric, in the mechanical view of the subject, is known simply as a force. Now, a force whose action does not imply, to the same extent, its extinction, in reference to the body to which it primarily belonged;—or a force which, admitted to become for an instant extinct in one body, by transmission to another, is the next moment capable of becoming self-recruited, are assumptions inconsistent with all natural phenomena, and involve a manifest impossibility. Yet the "caloric engine" is chargeable with this absurdity, so far as it is founded on the principle "that the production of mechanical force is unaccompanied by the loss of heat,"—and that "caloric can operate over and over again." In truth, it amounts to nothing less than affirming the principle of perpetual motion,—affirming that power can be gratuitously exerted, that it can be continued indefinitely in action, without exhaustion,—affirming, in short, that Newton's third law of motion is untrue, and that action and reaction are not equal and opposite.

The entire science of motion is implicated in this law of action and reaction, which certainly it is not necessary now to defend; but it is not a law of motion only—it is a universal law of Nature. All observations and experience prove, that qualities and quantities of all kinds, of a communicable nature, are in the very act, lost by one body, in proportion as they are received by the other. Take caloric, for instance, in its other aspect, as

simply a heating quality, and only as one body loses temperature is it able to impart it to another. But caloric, doubtless, is in all its aspects a manifestation of force, and unquestionably, as a mechanical agent, of a dynamic force, and therefore is directly amenable to the third law of motion. It is force, in the disguise of molecular action—it is atomic force, not yet converted into mechanical force—it is, in respect to either ponderable, or imponderable matter, a speciality of condition, appealing to the feeling of heat for its perception, but susceptible of being changed into another speciality, recognised by a sense of force, or power. As mechanical motion,—which is the motion of masses in their entirety,—can be and to be made useful, usually is transformed into molecular actions, such as those involved in heat and electricity, and in the rupture of cohesive force, so, through the medium of combustion, these transformations can be reversed, by first liberating molecular forces, and then fixing them in the entire movement of a mass, so as to be rendered available as a mechanical power. Now that peculiar molecular activity, which, by some mysterious process, creates the feeling of heat, is not susceptible of an increasing degree of intensity, except when the body is under the restraint of limits to its volume. Remove these—as can be done in an elastic fluid—and any further accession of caloric is no longer apparent, under the form of an increasing temperature, or of an increasing degree of repulsive force; but it makes itself visible in an increased range of this force—that is to say, the tension remaining constant, a dynamic force is generated, at the expense of this caloric, as its exciting cause. Thus mechanical force is developed simultaneously with a loss of heat, in entire conformity with the law of action and reaction. The usual phrase is, that heat becomes latent. The order and character, then, of these phenomena justify the inference, that what is at one time heat, is at another time modified into mechanical action, they being reciprocally convertible quantities, and in truth, the change of either into the other is matter of experiment. It follows, then, that sensible caloric is an indication, not of the presence, but of the abeyance of mechanical action,—not of its actual, but of its potential existence, and that a working force can appear, only as heat disappears. This is an important truth, although veiled somewhat by refinement of conception and nicety of distinction, for

which there is a want of an adequate terminology. This truth, so directly in opposition to the idea of caloric operating over and over again, is, however, apt to be overlooked, on account of the general familiarity with a display of heat, simultaneously and in intimate connection with the development of steam force. It thus appears, on a superficial view, that heat operates as a force, and at the same time exists as heat; whereas, heat appertaining even to steam in the cylinder, is not really acting, although ever ready to act in the production of elastic force, and ever vanishing in the process. This sensible heat of the working steam is, it is true, the necessary condition for maintaining the constant state of its tension, but it is not the efficient cause of force—it is not that which creates repulsion between the particles of steam, otherwise it would at all times be the direct measure of that repulsion, which it is not,—it is only an accompanying quantity of caloric, which when called upon by the permitted expansion of steam to do real work, is absorbed, becomes latent, and disappears. If this were not the true representation of the fact, caloric could be heat and force also, at the same time. This is the popular idea, and science perhaps has not been exempt from it, but if it were so, there would be no impracticability in the project of making it operate over and over again, and the creation of power, in the absolute sense of the words, would be within the capability of man.

There is a difficulty, however, which requires explanation, for it may be said in reply, that in the low-pressure steam-engine, all the heat that is contained in the steam, as it comes from the boiler, is to be found in the water of the condenser, although it has in the interim, generated power;—that the only question is, how to get it wholly back to the boiler, as it already is done partially, by the boiler being supplied with this heated water, and that the analogous problem is solved, when the motive medium is air, by the invention of the "regenerator." Undoubtedly in respect to the materiality of caloric,—if it be material, it is transferred intact to the condenser, yet in its passage it may have parted with force, which it cannot communicate again. It will be admitted, also, that in the aspect of temperature, the quantity of caloric, as estimated jointly with the quantity of water, will measure the same before and after the condensation of steam; but the change takes place, not in

the quantity, but in the intensity of heat. It is in the declination from a higher to a lower degree of temperature,—it is in the aspect of a *vis viva* force in caloric, that mechanical action is developed; in proof of which, if it be required again to raise the motive body to the higher temperature, recourse must be had, either to a further consumption of means, or to the employment, in the case of air, of the same amount of mechanical force in compression, as had been previously developed.

This explanation of the difficulty, may not, however, be satisfactory to a mathematician of the old school, who has been conversant only with that aspect of power, in which it is estimated by the product of force and velocity, and has not been accustomed to view it in the more practical light of mechanical efficiency. He would be inclined to say, that just as a mass, or force with a given velocity, is equal to a less mass, or force with a proportional greater velocity, so a body of water (that of condensation) raised a given number of degrees of temperature, is equivalent to a less body of water absorbing, in like ratio, a greater number of degrees of temperature. Thus no loss is found and yet power is developed. The answer is this; —as the efficiency of causes is known only by their effects, so they must be measured by their effects; and if by the same action of a cause, two classes of effects are produced, and if by the same variations in the action of the cause for both classes, it is discovered, that in one, the results, in the matter of cause and effect, are always equal to each other, and in the other class, that they are unequal, there must be two distinct and different measures enunciated, expressive of these facts. Now by the application of only one measure, to the operations of such a power, it may appear, that the cause is fully accounted for in the effect;—that reaction is equal to action, and yet a surplus fact, not of the same, but of a different kind, remains unexplained. The loss is seen to be balanced by the gain, yet extra results are acquired, and so the incautious reasoner, inattentive to the inviolable character of general laws, is led to conclude, that this acquisition has been effected, free of all cost. This apparent anomaly, or exception to the law of action and reaction, arises from the recognition of only one class of effects, when there are really two, and it disappears by the application of a second measure, supplementary to the first,

and appropriate to the nature of the second class of effects. This combination of measures, by embracing the whole of the case, subjects and reconciles it to the law in question. If the motive force be caloric, and if concurrently with a change from a higher to a lower degree of temperature, mechanical power is acquired, the inference is inevitable, that the latter is produced at the expense of the former; although by a measure, which takes no notice of this change, but recognises quantity only, there will not appear to be any loss. The idea of making heat generate mechanical power, and yet lose nothing itself, cannot be sound, as it must be ever ready to produce more power *ad infinitum*—a course of action, which if it were possible to prevail, as an ordinance of nature in her general operations, would soon bring the world to an end. This erroneous assumption is based on overlooking the change in the intensity of caloric, and of taking as the sole index of its action, the unaltered amount of its quantity.

The same diversity as to distinct classes of effects, and as to their appropriate measures, occurs in mechanics, and was the occasion of much controversy, among the mathematicians of the last century, as to the true measure of force. Both parties were partially right, although they differed materially in expression, for whether force be measured by time, or by space, they are both true measures under different conditions, although the physical circumstances be the same. It was reserved, however, for practical men to show, that the selection of the measure is not a matter of arbitrary choice, but that there is an appropriateness in the one, or the other, founded on the reality and utility of things. They forced into recognition the importance of another modification of power, besides that of momentum, or quantity of motion, and thus the names by which it is known, bear witness to its practical origin, such as "mechanical power," "work," "duty," "labouring force," &c. To them, also, practical science is indebted for a clearer idea of this aspect of power, by their having excluded from its definition and measure, the idea of velocity, or the element of time. Now the products of force by time, and of force by space, although taken in reference to the same physical action, yield different conclusions, as to the relation between power and its effects; the difference being in the ratio of the simple velocity,

to the square of the velocity, according as momentum, or mechanical action be contemplated as the effect. And so there will appear to be a discrepancy, as in the case of caloric, in regard to the law of action and reaction;—there will appear to be an equality, a deficiency, or an access, according as one, or the other formula is applied, and according to the mode in which it is applied to the admeasurement of causes and effects. But the third law of motion admits no exception,—if adequate reaction cannot be discovered by one rule, it may be by the other, which will thus be proved to be the true measure, for that particular aspect of the case,—to be the one appropriate to the nature of the change under review. The same law applies to caloric and its transformation, in the same manner as it does to motion and its transmission; there can be no gain without a loss, either in kind, in degree, or in something equivalent in the way of conversion. In short, heat, as indicated by its station on the scale of temperature, is as different physically, from heat measured by the number of its degrees, as momentum and working force are mechanically dissimilar; and as the former can be transformed into the latter, so by a greater transformation the molecular activity of caloric can be converted into mechanical power; but in no case can there be a development, or acquisition of any kind, without a corresponding loss; and yet as in the one case, so in the other, if the measure is not correspondent with the things measured, the loss may not appear commensurate with the gain, nay, it may appear, that no loss at all has been sustained, or a total loss without any gain.[1]

---

[1] These views admit of an easy illustration, by considering what takes place in the collision of two suspended balls, one of which is hard and the other inelastic, as of clay, for instance. Let the hard ball strike the other with a given velocity; then by the rule which measures the momentum of bodies,—namely, by the product of the mass, or force by the simple velocity,—it will impart to the clay ball, precisely that quantity of motion which itself loses in the impact. Thus action and reaction are equal and opposite, and limited to this particular view of the case, the cause is seen to be equal, but not more than adequate to the effect; yet it is undeniable, that as thus estimated, the whole of the action is not accounted for. The quantity of motion in both balls, is the same as existed in the acting one; although it is changed from a smaller mass with a greater velocity, to a larger mass with a less velocity; just as in the case of steam, when after being employed in the production of motive power, the quantity of caloric, as estimated jointly by temperature and the mass of water, continues the same, although it is changed from a

In opposition to all reasoning on the subject, an appeal in defence of the caloric engine may be made to its performances, and especially to the experiment which has been much insisted on, of the continued working of the engine, for some time after the fire has been withdrawn. Now on the alleged principle of its construction, it may fairly be argued, that it ought to perform a greater feat than this. If it be assumed, that the work

---

higher to a lower degree of the one, but from a less to a greater amount of the other. And yet, as in the case of steam, so in the collision of the balls, a certain amount of work has been done, although this mode of viewing and measuring the action does not in either instance ascertain it. In the latter case the work consists in the indentation made in the clay, or to put it in a more measurable form, in the driving in of a peg. Here, then, in the transmission of motion from one body to another, arises a surplus fact,—an extra result; and as much like an absolute gain, as the analogous mechanical action of the caloric engine is assumed to be, during the transmission of heat from one body to another, and apparently as equally destitute of any special cause, in which a corresponding loss can be traced. The truth is, the supposed gratuitous acquisition belongs to another class of effects, different in kind, and although ignored because it cannot be measured as momentum, is equally entitled to be considered a part of the action, which bodies exert on each other in collision. It is that part with which practical men are conversant, consisting of "work," and into which, generally, it is their object to transform all species of force; it has a measure of its own, in which time is excluded and space alone is considered. Now measured by this rule, causes and effects will be found to be mutually equivalents, as well under this aspect of causation as under the other; for the work done on the peg, in overcoming resistance through a certain space, will be equal to the product of the force and space in the raising, or falling of the ball. So also, in any variation of the experiment, the spaces will vary in like simple proportions; and in other cases, in which time must needs be introduced, in order to form an equivalent expression for the measure, the effect will vary as the squares of the velocities. Thus the law of action and reaction can in all cases be satisfied, provided a due discrimination is exercised, in regard to the character of the phenomenon, both in the cause and effect, and that the measure adapted to each kind, or class of motion, is appropriately, and not promiscuously, employed for each. In some cases, even three classes of motion may be conceived simultaneously to exist, in the same action; thus the falling ball may impart momentum to the other, drive in a peg, and shatter the end of it;—for the last effect, however, it may be difficult to find a common and appropriate measure. In short the most erroneous assumptions will not fail to be entertained, leading, as in the case of the caloric engine, to the idea of an effect without a cause, if the value of the entire action of a cause be estimated by only a portion of it; especially as in so doing, the measure employed must of a necessity be of a kind, appropriate only to the part recognised. It is scarcely a less error, if indeed it be not substantially the same,—although it is one into which mathematicians of the last century fell,—to take cognizance of only one class of effects, and insist on its measure, as being the only true and appropriate one.—AUTHOR.

to be done, be such as to afford, whatever the velocity, a constant resistance; then the friction and the radiation of heat being also constant quantities, the effect of the slightest excess of heat, beyond that lost by radiation, ought to be a progressive accumulation of force, until the engine knocked itself to pieces, by the rapidity of its movements. Indeed, a governor to such an engine, if the assumed principle were correct, should rather regulate its motion, by bringing into play an increasing resistance, than by the usual method of diminishing the power. Any force, extraneously imparted to the engine,—the caloric being assumed to operate over and over again,—would necessarily maintain the velocity unimpaired; whilst a slight addition of heat, would constitute an accelerating power, urging it on to its destruction. Still the doing of work by the engine, after the withdrawal of the fire, in a case where there is no large storage of power, as in the boiler of a steam-engine, is a somewhat paradoxical fact and requires explanation.

To utilize, to the greatest extent, a motive force generated by heat, the body should be brought down to the lowest temperature at command, through its own expansive action; for it is only in the reduction of temperature that force is elicited; so that all sensible caloric, remaining in the body, higher than this point, involves a loss of power. In the issue of steam from a non-expansive high-pressure steam-engine, both heat and elastic force escape to a considerable amount unemployed, and power is of course wasted. Now the caloric engine is analogous to a non-expansive high-pressure steam-engine, and consequently would be an exceedingly wasteful machine, if it were not furnished with some appliance, to recover either the heat, or the force of the escaping air. But these two factors,—the heat and the force,—do not imply a double loss, they being in truth, as before explained, convertible quantities; for if the body were allowed to expand, sensible heat would be absorbed and utilized; and conversely, if the heat were otherwise absorbed and utilized, it would be an equivalent for the expansive force of the escaping air. This, then, is the office of the "regenerator;" for expansion is not a practical expedient in this engine, because, among other reasons, of the low tension of the motive force. The "regenerator" is not what its name imports, nor is it exclusively a condenser, but it recovers unap-

propriated force, by absorbing unutilized caloric. It is this recovered sensible heat, which otherwise would have been wholly wasted, that is made to operate,—not over again,—but through another opportunity afforded it, in conjunction with fresh supplies of caloric, to generate force. The great efficiency of this office of the "regenerator," is due to the process being conducted *per gradum*, instead of *per saltum* as in ordinary condensation; by which means, much of the sensible heat is recovered at a higher temperature, than could be otherwise effected;—a construction, for which Captain Ericsson is indebted, both for principle and practical means, to the Messrs. Stirling. Now because of the difference in latent heat, and the very high temperature of the caloric engine, the sensible heat of the escaping air, bears a much larger proportion to the efficient, or force generating caloric, than in the case of steam. Hence the loss of power, by the waste of the sensible heat, would be enormous; and therefore the recovery of it by means of the "regenerator" constitutes a considerable power, relatively to that of the engine, and is sufficient, aided by the inertia of the parts, to keep it in work with a decreasing speed, corresponding to a decreasing temperature, for a considerable time, even after the fire is withdrawn; especially as the "regenerator" more effectually answers its purpose, under these circumstances, than in the ordinary working of the engine, on account of the greater exhaustion of its innate force, in the decreasing temperature of the air. Thus this paradox receives an easy solution, without resorting to the questionable hypothesis of a regeneration of force.

That Ericsson's engine may be an efficient one is not disputed, but its merits must rest on common ground with those of the steam-engine. The great question is, whether an economy of fuel can be effected, and this is not an improbable claim. Some thirty years since when engaged on a project of this kind, the Author calculated, that an air-engine would be more efficient with a given quantity of caloric than a steam-engine, in the proportion of 1·24 to 1·0; but doubtless a calculation founded purely on theoretical data, would give in this, and in all cases of gases and vapours, the ratio of equality; for every investigation leads to the conclusion, that the effect of caloric, is independent at least of the chemical, if not also of the phy-

sical constitution of bodies. But economy of fuel is a different question from the economy of caloric; it is altogether a practical matter, and can only be determined by experiment; for this, and indeed most other points of practice, are too intractable to come within the grasp of the most powerful calculus.

The economy of fuel, as a distinct subject from that of caloric already in possession, has scarcely met with the attention it deserves, except in Cornwall, and there only in regard to one particular view of it,—the management of the furnace. It was observed, during the experiments of Mr. Perkins on high-pressure steam, that whilst he was intent on economising caloric, by carrying the pressure to an extraordinary degree, he allowed the upper part of his chimney to become red hot. But without entering on the subject of the construction and management of furnaces, there is a theoretical point connected with it, which deserves attention, as being relevant to the question under discussion.

Let the possibility be admitted for a moment, of the whole of the caloric developed by combustion in the furnace, being absorbed by the water in the boiler; still it will follow,—from what has been already stated, as to mechanical power resulting, solely, from a difference in the intensity of caloric,—that a large amount of fuel would be wasted; for between the temperature of the furnace and that of the water, even in Mr. Perkins' "generators," there is a great interval, within the range of which, no means are taken to elicit power. By going higher up towards the fountain of power, it may not be impracticable to appropriate it between variations of temperature, where, for want of a proper motive agent, it is now lost, simply because it is neglected. The experiments of Mr. Perkins were therefore made in the right direction, although unwittingly, for he had another object in view. But it is to be greatly doubted, whether water is so constituted as to render it a suitable body to receive very high degrees of temperature, with the requisite facility. Considerations, not now to be entered on, connected with the state of repulsion that is then manifested;—the comparative immobility of water under great pressure, as interposing an obstacle to the rapid communication of heat;—the many important points of a practical kind, involved in the action of steam, under very high pressure, all seem to disqualify water for

being a motive agent, at a higher temperature than is usually adopted. But the use of air, in a highly-heated state, is not encompassed with these difficulties, although it may have others peculiar to itself. The experiments both of Captain Ericsson and of the Messrs. Stirling testify, that it can be conveniently heated up to more than double the temperature of steam; and in this there is not of course involved any dangerous pressure, which may indeed be just what the operator chooses to make it, or may find easy to manage. The arrangements for the production of the hot-air blasts at the iron works, prove also, that heat at a very high temperature, probably approaching 1000°, can be communicated to air with all necessary rapidity; but to make it available, in this state, for the development of power, would be a very difficult practical problem.

If these considerations be based on sound premises, and if it shall hereafter be found, that a saving of fuel does result from the employment of hot air as a motive power, such saving must be principally attributed to the passing of the air through a doubly greater range of temperature, than in the case of steam, during which, at every moment of gradation, intensity of caloric changes into force. On the other hand, the immense surfaces which are, in practice, exposed to the radiation of heat, by the cylinders being so very large, in proportion to the power of the engine, must entail a great loss of heat; so that after all, the final result must be left to be determined by experiment, and if the saving of fuel be not found very decidedly in favour of heated air, steam power will continue to be preferred, on account of the superior compactness of the engine.

Mr. G. Crispe said, after the philosophical toys of the early experimenters, the first approach to a practical caloric engine was that invented by Sir George Cayley (Assoc. Inst. C.E.), and described in Nicholson's Journal in 1807.[1] For many years his attention was almost exclusively devoted to the subject, and eventually, in 1837, one of these machines was reported by Mr. Goldsworthy Gurney and Mr. G. Rennie (M. Inst. C.E.), to be doing a duty equal to 5 H.P., with an expenditure of 20 lbs. to 22 lbs. of coke per hour. The chief defects appeared to be the difficulty of lubricating the piston, and the abrasion of the working parts, from the dirt apparently inseparable from the air, which had passed through the incandescent fuel.

In 1816, the Rev. Dr. R. Stirling took out a patent for an air-enginé,[2] differing in all important particulars from that of Sir G. Cayley. The new machine resembled the steam-engine in the construction and arrangement of many of its parts, such as the cylinder, piston, piston-rod, parallel motion, beam, crank, &c. Motion was obtained, by heating the air in communication with one side of the piston, and cooling that in connection with the other, by which means a difference of pressure was obtained upon the opposite sides. The air was alternately heated and cooled, by having the air-chambers, one of which was connected with the top, and the other with the bottom of the cylinder, fixed respectively over two fires, by which their lower ends were kept at a temperature of about 600° Fah^{t}., whilst their upper parts were kept cool; the air, by the aid of a plunger, being made to occupy the top in one chamber, and the bottom in the other, alternately. Dr. Stirling also introduced and patented at the time, what had since been called the "regenerator," the object of which was to save a portion of that heat, which would otherwise be lost in cooling the air at each stroke of the engine: it consisted of a series of laminæ of metal, between which the heated air passed, in its progress from the bottom to the top of the air-chamber. The metallic surfaces became heated by contact with the air, which heat they retained, until the air, in its return from the top to the bottom, in its cool state, had to make its way through them, in the opposite direc-

[1] Vide Nicholson's Journal, vol. xviii., November, 1807, page 260.

[2] Vide "Repertory of Patent Inventions," vol. xxx., page 63. Date of Patent, November 16, 1816.

tion; in the return stroke it took up from them the heat which they had just received; and in proportion to the amount of heat kept back, by those means, was the saving of fuel effected. Another patent was taken in 1827 by Messrs. R. and J. Stirling.[1] An engine of the kind described was erected at the Dundee Foundry in 1843, and continued to do the work of the establishment for about four years. Mr. Stirling in describing the machine, at a meeting of this Institution in 1845,[2] stated that the economy of fuel in using the air-engine in place of steam was as 6 to 26.

Mr. Stirling had recourse to surrounding the cylinder with water, for the purpose of cooling the air, and it was evident, that one of the main features of his invention was the "regenerator," for which he at first used wire gauze, then he tried metallic discs, and at last he adopted metal plates. Whether the theory of this "regenerator" was practically borne out, or not, there could be little doubt of the invention being due to Messrs. Stirling, and up to the period of the announcement of the caloric-engines on board the 'Ericsson,' they had certainly obtained the most satisfactory results.

In 1827, Messrs. Parkinson and Crosley, well known as the inventors and manufacturers of the gas-meters bearing their name, patented a modification of the air-engine.[3] It consisted of a close cylindrical air-chamber, with its plunger piston, immersed midway in cold water and a ring of jets of gas encircling its upper part; the piston rod traversing by a stuffing box. Connected with the upper part was a working cylinder, open at the top, but with a piston and rod fitted within it. The air contained within the chamber, when at the top, being heated by contact with its hot sides, was in consequence expanded. A portion making its way through the opening into the working cylinder, pressed the piston upwards. By a proper communication of parts, this was made to give motion to the plunger, so that by the time the piston was at the top of its cylinder, the plunger had reached the top of the air-chamber.

---

[1] Vide "Repertory of Patent Inventions," vol. vi., page 100. Date of Patent, February 1, 1827.

[2] Vide "Minutes of Proceedings Inst. C. E.," 1845, vol. iv., page 348.

[3] Vide "Repertory of Patent Inventions," vol. vii., page 414. Date of Patent, August 1, 1827.

The result was evident, the air made its way down past it to the cold end of the chamber, became cooled and contracted; the piston descended, and after it the plunger: so that the operation might be repeated *ad infinitum*. It had only been tried as a model, but the rapidity with which the model worked was very remarkable. The speed was usually kept down to about 150 strokes per minute, although there seemed no reason to doubt that it would make 1500 strokes, if the experiment were ventured on. It was instructive, as showing how rapidly air might be heated and cooled.

In 1826 Lieutenant (now Captain) Ericsson, a native of the province of Vermeland, in Sweden, came to England for the purpose of introducing an air-engine, which he had invented; but, after using every exertion, the difficulties were found to be too great, and the project was soon abandoned.

He tried a long series of experiments upon a machine of considerable dimensions at the works of Messrs. Braithwaite and Co., and placed on record in the archives of this Institution the results of his invention.[1]

In 1850 a modification of the system was patented by Captain Ericsson, under the name of Edward Dunn,[2] and that machine, as now improved, was, it appeared, now erected in the caloric ship "Ericsson."

The general construction of the modern caloric-engine, as given in the descriptions transmitted to this country, was a working cylinder, beneath which a fire was made to elevate the temperature of the air within it. Under the piston of the cylinder a vessel was fixed and filled with non-conducting materials, called the heat-interceptor, its office being to prevent the heated air from coming in contact with the main body of the piston, and thus to keep it cool—an expedient which was adopted by Sir George Cayley for the same purpose, in connexion with his air-engine, and patented by him in 1838. Inverted above the working cylinder was the air-pump, or supply-cylinder, with its piston and valves, the relative areas of the upper and lower

[1] Vide O. C., No. 119, "Description of a new method of employing the Combustion of Fuel as a Motive Power," by T. Ericsson, 1827.

[2] Vide "Repertory of Patent Inventions," vol. xviii., page 93. Date of Patent, December 26, 1850.

cylinders being as 2 to 3. Air being taken in through one valve from the atmosphere, and discharged through another valve into the receiver, placed at the side, and communicating with the top of the upper cylinder and the bottom of the lower, or heating-chamber, by the slide-valve, which could be closed at pleasure.

When the slide-valve was closed, to prevent a communication between the receiver and the working cylinder, it, at the same time, opened a communication between the working cylinder, and the atmosphere under the valve, and through an opening into the regenerator, consisting of a number of layers of wire gauze, through which the air had to pass, both in its entrance to, and exit from, the cylinder.

The *modus operandi* of the engine was this: the engineer, having seen to the lighting of the fires, permitted the temperature of the lower part of the cylinder and the parts adjacent, to reach a temperature of 540°; then closing the slide-valve, he proceeded, with a hand-pump, to force atmospheric air into the receiver, until it had attained a pressure of some few pounds to the square inch. These arrangements completed, everything was ready for starting. He then, by the aid of such hand-gear as was usual in steam-engines, threw the slide-valve into such a position as would allow the compressed air to make its way into the working cylinder.

Imagining, then, everything to be perfectly cold—regenerator, fire, supply-cylinder, all removed; still, upon opening the slide-valve (as before described), the piston in the working cylinder would be elevated. When it had reached the top of its stroke, let the slide-valve be closed: no more air could then enter, and that already within the cylinder would make its escape under the slide-valve into the atmosphere, and thus allow the piston to descend by its own weight. When it once more reached the bottom of the cylinder, if the slide was again opened, there would be a repetition of the action just described; and this might evidently be repeated, as long as the necessary supply of air could be maintained in the receiver, precisely as a high-pressure steam-engine continued to work, whilst steam was supplied from the boiler.

But since as much air must be supplied to the receiver, at each stroke of the engine, as was removed by the working cylinder, if

the air in that cylinder were of the same temperature as the air supplied to the receiver, a pump must be employed for the purpose as large as the cylinder itself, and more power would, in consequence, be required to work it, than the compressed air could possibly give. By the application of heat, however, every cubic foot of air, forced in by the pump, was doubled in volume, consequently the power required to work it was reduced, because a pump of smaller size answered the same purpose, and thus a surplus of available power was obtained.

The office of the heat, then, was not to increase the pressure of the air, when once it had entered the working cylinder (this, under the circumstances, it could not do), but, in reality, to increase its volume with the elevation of the large piston, thus making the same quantity of air fill double the space, and yet keep up the original pressure of the cold air pumped into the receiver.

The 'regenerator'—a very important feature in the contrivance, remained yet to be spoken of. As before stated, it consisted of a series of layers of iron-wire gauze, through the meshes of which the heated air had to pass, in its passage from the cylinder to the atmosphere, and which, as it came in contact with each successive layer, parted with more and more of its heat, until, before it quitted the last, it was said to be not more than about 30° or 40° hotter than the atmosphere itself. The heat left by the escaping air was supposed to be distributed in the regenerator, in such a manner, that next the cylinder the temperature was almost equal to that of the air within, whilst next the slide-valve it was but little above that of the external air.

The heat, thus taken up by the regenerator, was retained by it, until the piston, having reached the bottom of the cylinder, a fresh supply of air was allowed to enter it from the receiver; this cold air, in its passage through the regenerator, became heated, as the escaping air became cooled, by contact with the metal surfaces, and consequently entered the cylinder with its temperature considerably elevated, requiring, in consequence, so much less heat to be imparted by the fuel employed.

It was, however, contended by the opponents of the system, that the action could not be such as was stated, and that the regenerator could not make any difference to the amount of fuel employed. It was to be regretted, that those who took this view

had not yet offered any adequate philosophical reason for their opinion, because, when once it was fairly shown, that there was some natural law opposed to it, the question was settled, and much valuable time and money would be saved. In the absence of this the question must be examined *pro* and *con*, as it was now popularly presented. The air in the cylinder had a temperature of say 540°, *i. e.*, about 480° above that of the atmosphere—at which temperature, according to Dulong and Petit, its original volume was doubled; upon escaping into the atmosphere, through the regenerator, from the fact of its having been employed in the cylinder under pressure, it expanded, and in so doing took up a certain amount of heat in the latent form (about 8 degrees for every pound of pressure). For instance, if the air in the cylinder had a temperature of 540°, and a pressure of 5 lbs. per inch, above that of the atmosphere, upon expanding to the pressure of the atmosphere, it would exhibit a temperature of 500° only, the 40° having become latent. Now since the air could not, by contact with the metallic surfaces, make them hotter than itself, it would at once appear, that these 40° of heat were lost, but the 500° remaining were tangible heat; which, for comparison, might be likened to that of hot iron,—heat which could be measured by a thermometer, and which would pass from one body to another by contact. If then the layers of wire gauze, through which the air had to pass, were of a low temperature, this air would assuredly pass out from it at a lower temperature than it entered. And it could not be doubted, that if cold air was made to pass through the hot gauze, its temperature would be raised, and that so much heat as it received in this way, so much less would the fuel have to give. In reference to either the quantity, or pressure of the air in the cylinder, it would be seen, that it made no difference whatever, whether it was heated by the regenerator, or by the bottom plates of the cylinder itself. The question might arise, however, whether the air, in passing through the gauze at the rate of 12 feet per second, had time to yield up, or to take up the heat in any quantity; in reference to this, the rapidity with which the air was capable of being heated and cooled in Parkinson's engine, had been already referred to, and many other examples of a similar character were familiar to engineers.

The practical objections to the general arrangement of the engine were numerous, and of such a character as, even supposing all others to be removed, would doubtless prove fatal to its ultimate success. For instance, the theoretical effect due to the air in this engine,—supposing it to make ten strokes per minute, and its volume to be doubled by heat,—was 763 H. P. Its actual effect in the working cylinder should be 600 H. P.; and out of this, 374 H. P. would be required to work the pump, leaving available only 226 H. P., or less than one-third of the power due to the air. Again, from the fact of the pressure obtainable being small, and operating only upon one side of the piston, it became necessary to have an enormous extent of piston surface. In the 'Ericsson,' for instance, four engines, such as that described, were employed with working cylinders 14 feet in diameter; also four air-pumps, or supply-cylinders, each between 11 and 12 feet in diameter, creating a vast amount of friction and liability to leakage; and in a case, be it remarked, where leakage was of the utmost importance. It was not possible, as in a steam-engine, to push on the fires to overcome the difficulty, as such a proceeding, carried beyond a certain point, would evidently be fatal to the heating-vessels. Mr. Stirling was compelled to abandon his engine, chiefly on account of the difficulty experienced in preserving his air-vessels. The plan which Captain Ericsson at present employed for heating them, was the same as that which Mr. Stirling commenced with thirty years since, and which he afterwards greatly improved upon, and yet failed. There was then no apparent reason for believing, therefore, that, by the present arrangement, Captain Ericsson could be more fortunate than his predecessor.[1]

---

[1] At the meeting of the British Association, at Liverpool, in September 1854, Mr. W. J. Macquorn Rankine, Assoc. Inst. C. E., read a paper "On the means of realizing the advantages of the Air Engine;" in which were explained the fundamental laws of the mechanical action of heat, and their application to determine the efficiency of theoretically perfect engines, working between given limits of temperature; then the "various causes of waste of heat and power in steam-engines were classified, and the actual efficiency of steam-engines was compared with their maximum theoretical efficiency, and also with the maximum actual efficiency, which might reasonably be supposed to be attainable in the steam-engine, by means of any probable mechanical improvements.

"The causes of waste of heat and power in air engines, were then classified in a manner analogous to that applied to steam-engines; and the actual effici-

Mr. GOLDSWORTHY GURNEY said it was well known, how long Sir G. Cayley's attention had been devoted to the subject of using heated air as a motive power; indeed the air-engine might be said to have originated with him. Sir George Cayley was prevented by indisposition from coming to London, to be present at the discussion, but he had transmitted to the Secretary, a few remarks, which had been understood to have received the approval of the Council, and Mr. Gurney would therefore ask that they might be read to the meeting.

The SECRETARY, by permission of the PRESIDENT, then read the following:—

"Remarks on the Use of Heated Air as a Motive Power.
By Sir GEORGE CAYLEY, Bart., Assoc. Inst. C.E.

"The free power of Captain Ericsson's engine, arises from the difference of the areas, of the hot and the cold pistons; both receiving, in opposition to each other, during their combined

---

encies of those previous air-engines, as to which satisfactory experimental data had been obtained, namely, Stirling's engine and Ericsson's engine of 1852, were compared with the efficiencies of theoretically perfect engines, working between the same limits of temperature, the results, so far as they related to the consumption of coal of the specified quality per horse-power per hour being:—

	Actual Consumption.	Consumption of a Theoretically Perfect Engine.
Stirling's engine	2·20 lbs.	0·73 lbs.
Ericsson's engine	2·80 ,,	0·82 ,,

"Thus showing that an air-engine had actually been made to work successfully, and economically.

"A description was then given of the improved air-engine of Messrs. J. R. Napier and W. J. Macquorn Rankine. In this engine, the heating surface was increased to any required extent, by means of tubes employed in a peculiar manner. The waste of heat, by its communication to the air, at improper periods of the stroke, was prevented by a sort of plunger called the heat-screen, which prevented any access of the air to the heating surface, except when it was in the act of expanding, and so performing work. The engine might be made of the same size with a steam-engine of the same power, or smaller, according to the degree of condensation at which the air was employed.

"Independently of the amount and value of the saving of fuel, which would result from the introduction of the air-engine, it possessed the important and incontestable advantage, that even should an air-receiver burst (which was very unlikely), the explosion would be harmless, for its force would not be felt beyond the limits of the engine itself, and hot air did not scald." In the Mechanic's Magazine of October 21, 1854, there is given a diagram and short description of this engine.—EDITOR.

stroke, an equal average pressure per square inch, from an equal head; but the conditions of the case are such, that neither piston receives a uniform pressure during the whole of its stroke.

"When the cold air is doubled in bulk, by a temperature of say 530°, a head of 15 lbs. per square inch is obtained; and this head must be kept up for the uniform working of the engine: hence, (this head having been previously generated, for starting the engine, by injecting water on the fire, or by mechanical condensation,) only an equal weight of hot air can be permitted to escape at each stroke, with that of the cold air driven in.

"The cold pump, working against a head of 15 lbs. per square inch, will move half its stroke, gradually condensing the air within its cylinder, at an average of about 7½ lbs. It then proceeds for the other half of its stroke, against the head of 15 lbs.; averaging 11·25 lbs. to the square inch, for the whole stroke.

"On the other hand, the full pressure of 15 lbs. per inch is allowed to operate on the hot piston, for the first half of its stroke, when the supply from the head must be cut off; and the remainder be performed, under the gradual diminution of the pressure, by expansion. So that at the end of the stroke the air passes out at par with the atmospheric pressure. Here, as in the former case, half the stroke is done at 15 lbs., and the remainder at 7½ lbs., averaging 11·25 lbs. per square inch, as before. Thus the two pistons keep the same ratio, in the average of their strokes, though in the reverse order, as to the increase and decrease of the pressure upon them. Hence, as before remarked, the free power of the engine is as the difference of the areas of the pistons, multiplied by the average pressure upon them (not by the full pressure of the head) minus the friction on both: and again by the number of strokes per minute, and the length of each stroke.

"From whatever source the heat be supplied, that expands the cold air to double its bulk, the expansion must have the same dynamic effect. Hence the case of the regenerator, as applied by Captain Ericsson, is reduced merely to the following consideration. Does caloric, generated by combustion, differ from itself, after being applied to a solid metallic body? Suppose a mass of red-hot iron taken out of a fire, to be put into a vessel full of cold air, will it, or will it not expand it just in

proportion to the heat communicated by conduction? By what process do steam-engines work, but by iron plates, heated by fire on one side, and transmitting that heat to water, and its steam on the other? The tendency of heat, is, with reference to mere temperature, ever to equalise itself with all contiguous bodies, according to their specific demands; and this can only take place, by its being communicated from one body to the other. Steam-engine power to some extent depends upon the heated air in the fire-flues, being cooled by the iron sides, or pipes of the boiler, in generating the steam; thus the heat of the air, from combustion, is transferred, and being so transferred, it creates power. In what then does this case differ, in principle, from the metallic meshes of Captain Ericsson's engine, heated by a similar flow of hot air? There can exist no doubt of the effective re-application of heat to an almost unlimited extent, by this beautiful invention, due originally to Mr. Stirling, and now carried out to a greater extent by Captain Ericsson.

"The approach to perpetual motion by this repetition of the action, has been considered as a refutation of the principle; but it must be recollected, that a principle of perpetuity pervades some of the most simple acts under natural laws. When a billiard ball is propelled on a smooth horizontal plain, if it were not for the resistance of the air and friction, the law of its nature would cause it to roll on for ever. The slight escape of heat from the imperfect non-conductors used in the caloric engine, resembles the friction that prevents the action of the rolling ball from being perpetual. A perfect non-conductor of heat, would render the case as nearly interminable, as the very slight loss of it, by the current of air, in its exit, not having had full time to divide its ultimate extra caloric with the last series of meshes, would permit.

"There are, as has already been observed, several difficulties attending the construction of air-engines. The main one is the bulk of the cylinders, and other parts of the engine to make good the small pressure per square inch, that can be obtained without extra condensation, which is objectionable on account of the leakage it occasions.

"Another objection, is the heat the pistons may be exposed to, without considerable precautions being taken to prevent it.

"The dust from the coke was, in some constructions of the

first air-engines, where the whole heat generated by combustion, was received by the air in an air-tight generator, found inconvenient for the sufficient lubrication of the pistons, although in a great measure shielded from the heat, by the plungers. It may prove difficult to combine the economical production of heat, by consuming the fuel in an air-tight vessel; with the principle of its continued application by the regenerator, as the fine wire meshes may get so clogged up by the loaded vapour, or, external oxidation, as to impede that rapid absorption and restoration of caloric, on which their efficacy depends; but it must be hoped that even such a primary result, will not eventually prove beyond the remedy of chemical science, applied with mechanical skill; and should this combination be ever practically carried out, the consumption of fuel in the air-engine will be reduced to an infinitesimal quantity. The attention of some of the members of this Society, will therefore not be ill-directed, when applied to the utmost practicable improvement in the means of using air as a motive power.

"For locomotive purposes, on shore, it seems probable, that steam and air can only come into competition with each other, by their expansion—the weight of water necessary for the condensation of the steam; and the slowness with which air can be cooled, render both inapplicable, by condensation, for speedy locomotion.

"When water has been converted into steam, from its mean temperature, by the application of 1127° of heat, it may then, if the supply be cut off, be doubled in volume, under atmospheric pressure, at a temperature of 692° (212° + 480°), a very inconvenient heat for any piston, and if steam has to be brought up to this temperature, by an external fire, and its flues, the whole of the air heated by combustion must part from the boiler, under the best construction, at a temperature rather exceeding 692°; a heat considerably greater than that required to work the air-engine, is, therefore, in this case, totally wasted. But steam will exceed atmospheric pressure (15lb. to the square inch), when remaining in contact with the boiling water, at a temperature of 250°, when its density is very nearly doubled, and the caloric required is increased in much the same ratio; it is, therefore, by far the most economical way to form steam, required expansively, by using the air-tight generator, and

driving the whole heated air, in streamlets of minute bubbles, rising through the water. The difficulties, as to the dust and the heat of the pistons, stated to have been experienced, only had reference to the engine of 5 H.P, then under notice at Millbank.

"The report of the meeting of June 10, 1845, is incorrect in two points. It is there stated, that the slide-valves were torn by the dust (which was correct), and that the conical valves, though, in some degree, avoiding the evil, were considerably abraded, also the passages, the pistons, and the cylinders were destroyed by the heat and dust. It is true that the pistons were injured, but neither the cylinders, nor passages, nor conical valves were hurt. It is stated also that the evil of the heat of the piston was attempted to be obviated by appending a drum "below the piston;" now this drum, or plunger, was placed above the piston in every engine made, and therefore, could not have been spoken of as being below it.[1]

"A one horse-power engine, previously made, had very little, if any, of these defects, and it was from two accidental circumstances a much better engine, though prior in the order of construction. The hot cylinder, being made of sheet copper, which cools with double the rapidity of iron, and much more than double in this case, from the quadruple thickness of the iron ones, kept the working part of the piston from injury, aided by the plunger; and the more than double area of the generator, in proportion to the air driven through it in a given time, nearly cured the evil of dust; it had also conical valves, which were quite uninjured.

"From circumstances distinct from the nature of the evils the Millbank engine had shown, and which probably a water-jacket would have much remedied, no further experiments were made with it.

"The one-horse engine, when examined by Mr. Gurney, worked perfectly well for several days in succession, while being tested by friction both to ascertain its power and its consumption of fuel. It is no bad omen that so small an engine, where there was so much more heated and rubbing surface, in proportion to its power, than in larger engines, without any attempt

---

[1] Vide Minutes of Proceedings, Inst. C. E., 1845, vol. iv., page 359.

to economize heat by non-conducting covers, should have produced a horse-power by the expenditure of 7 lbs. of coke per hour. It is right to state these matters, that a true view of the case may not be wanting, towards a further experimental investigation of the subject. The exact particulars of this engine are these:—

"In the single-horse engine;—the cold piston 10½ inches in diameter; the hot one, 13½ inches, both a foot stroke; the fire-place 10 inches in diameter, by 11 deep, within a generator containing about 20 cubic feet of air; head of pressure, by mercurial gauge, from 8 to 9 lbs., made ninety strokes per minute, that is, ninety revolutions of the fly-wheel. The weight of 550 lbs., raised one foot high, per second, being taken as the test of one-horse power.

"The air, or mixed air and steam engines, with the internal combustion of the fuel, may be made to imitate animal muscular power, in as instantaneous and violent an increase of action, by a small jet of water on the fire; this instantly produces the effect for a limited time. Oil of tar, or other inflammable fluids, might perhaps prolong this action considerably."[1]

---

[1] Although the experimental air-engines have not had the advantage of Mr. Stirling's, or Captain Ericsson's renovators of heat, yet having made use of all the heat generated by the combustion taking place within the reservoir, containing the head of expanded air, very much compensates for that deficiency, and is undoubtedly the most economical way of communicating heat to the air. Theoretically, according to present chemical data (at the particular degrees of caloric and condensation specified), it would require about one pound and a half of dry charcoal to sustain one horse-power for an hour, by the expansion of air, were there no loss by external cooling: and although the products of this internal combustion may render the application of Captain Ericsson's wire-gauge meshes more difficult; yet the economy in generating the caloric is so great, as will probably render this ultimate refinement of the engine of more cost and trouble than advantage, in a mercantile point of view.

Engineers should be induced to carry out the internal combustion principle, at present, and subsequently to test the Ericsson principle, in connexion with it. The plunger, which is almost an indispensable part of the air-engine, as by its means the working portion of the piston may be kept at any required moderate temperature, deserves some notice; as experience has proved, that hitherto it has never been taken advantage of to the proper extent. It was first thought of and applied by Sir G. Cayley to the engine made in the year 1837. It was not, then, perhaps, longer than half the stroke; in the subsequent engines it has been elongated to be rather more than the length of the stroke; but although it is a troublesome and weighty appendage, there is reason to believe, that it would be advantageous to make it double the length of the stroke.—G. C.

Mr. Goldsworthy Gurney resumed:—It was almost needless to enter into the question of Sir G. Cayley's engine, after the remarks that had been read. It was however incumbent on him to corroborate their correctness. In the improved engine there was little inconvenience from the dust, and after the conical valves were adopted there was little trouble from abrasion. The consumption of fuel was about 6 lbs. of coke per horse-power per hour.

The destruction of the heating vessel was the principal difficulty; the same radical defect must exist in Ericsson's engine, as the plates must be heated to upwards of 500°, or else the air would not attain the necessary temperature. The difference of area between the two cylinders would be found a practical difficulty, and unless some modification of the machine was adopted, something like cutting off the steam at a portion of the stroke, the available effect of the expansion of the air by heat, would be in a great measure lost. The action of the regenerator, rapidly absorbing and giving out heat, was very remarkable, and afforded an important auxiliary. Considered as a whole, the arrangement devised by Sir George Cayley was, Mr. Gurney thought, superior to that of Captain Ericsson. In Sir G. Cayley's engine, the air was heated by actual contact with the incandescent fuel. The destruction of the heating vessel, common to all air-engines heated externally, was therefore avoided in this engine, where the combustion was confined to an internal fire-place, much modified, and in which any injured part could be readily renewed.

To use economically the power of air expanded by heat, the supply must be cut off from the power cylinder, as fully explained in the letter just read. The early accounts were written and published in the 'Philosophical Journal' for 1817, several years after the first experiment had been tried at Newcastle, where the engine was so ill-executed and leaky, as to show no free power. All the principles since applied in the subsequent engines, excepting that of keeping the working piston cool by a plunger, were fully developed in the diagram of the engine then given—even the arrangement adjusted by Capt. Ericsson of placing the cold-air pump, and hot-air power piston, on the same rod, were shown. The plunger, which was almost a *sine quâ non* in every air-engine, was employed in the one-horse power engine made in 1837.

Mr. H. Maxwell Lefroy stated, that his attention having been directed to this subject by Mr. Gordon, he had made an investigation of the quantity, volume, and elastic force, of the gases into which 1 lb. of Jones' anthracite coal was decomposed by combustion, on the assumption that the whole caloric developed by the combustion of the coal should be received and retained by the gases.[1]

The constituents of 1 lb. of this coal, as given in Sir H. De la Bèche's Report on Steam Coal, were,

	lbs.
Carbon	0·9144
Hydrogen	0·0344
Nitrogen	0·0021
Sulphur	0·0079
Oxygen	0·0258
Ash	0·0152

One part of carbon combining with 2·66 parts of oxygen, the carbon above given would be converted into $0{\cdot}9144 \,\{1 + 2{\cdot}66\} = 3{\cdot}346$ lbs. carbonic acid.

One part of hydrogen combining with 8 parts of oxygen, the hydrogen above given would be converted into $0{\cdot}0344 \,\{1 + 8\} = 0{\cdot}3114$ lbs. of steam.

Twenty-one parts of oxygen combining with 78 parts of nitrogen in the atmosphere, the nitrogen, combined with the oxygen which would be required for the combustion of the carbon, would be $0{\cdot}9144 \times 2{\cdot}66 \times \frac{78}{21} = 9{\cdot}055$ lbs.

Similarly, the nitrogen combined with the oxygen required for the combustion of the hydrogen, would be $0{\cdot}0346 \times 8 \times \frac{78}{21} = 1{\cdot}029$ lb.

Therefore the total nitrogen, which would be forced into the closed furnace, in combination with the oxygen required to support the combustion of the carbon and hydrogen, in 1 lb. of that coal, was $9{\cdot}055 + 1{\cdot}029 = 10{\cdot}084$ lbs.

---

[1] The MS. of this portion of the discussion was corrected by Mr. Lefroy, but in consequence of his departure from England it was not possible to submit the proof to him; the calculations, therefore, remain as in the original MS.—Editor.

13,268 units of caloric were developed by the combustion of 1 part of carbon.

Also 62,470 units of caloric were developed by the combustion of 1 part of hydrogen.

Therefore the heat developed by the combustion, that is, the conversion into carbonic acid and steam, of the above given quantities of carbon and hydrogen, would be $0{\cdot}9144 \times 13268 + 0{\cdot}0346 \times 62470 = 14092$ units.[1]

The pressure being constant, the relation of volume and temperature of a constant quantity of any gas, was defined by the formula $V_1 = \frac{459 \times t_1}{459 \times t_2} V_2$ where V_1 t_1 V_2 t_2 respectively were corresponding values of the volume and temperature in degrees of Fahrenheit. As the carbonic acid, nitrogen, and steam occupying the same space (the closed furnace) would have a common temperature, the 14092 units of caloric must be absorbed by these bodies, in the proportion of the products of the quantities of the bodies and their specific heats, respectively.

Therefore, if x = the caloric received by the nitrogen, $\frac{x \times 3{\cdot}346 \times 0{\cdot}2210}{10{\cdot}146 \times 0{\cdot}2754} = 0{\cdot}2649\,x$, would be the caloric received by the carbonic acid, and $\frac{x \times 0{\cdot}3114 \times 0{\cdot}8470}{10{\cdot}146 \times 0{\cdot}2754} = 0{\cdot}0946\,x$, the caloric received by the steam.

But the sum of these quantities of caloric was 14092 units.

Therefore $x\ \{1 + 0{\cdot}264 + 0{\cdot}0946\} = 14092 \therefore x = \frac{14092}{1{\cdot}359}$

[1] By unit of caloric, throughout this investigation, was meant the quantity which would raise the temperature of 1 lb. of water from 39° to 40° Fahrenheit, that is, by one degree measured at the temperature of maximum density.

The specific heat of steam was assumed to be .	0·8470
,, ,, nitrogen	0·2754
,, ,, carbonic acid	0·2210
The volume of 1 lb. of steam	27·66 cubic feet.
,, ,, atmospheric air . . .	13·02 ,,
,, ,, nitrogen	13·1 ,,
,, ,, carbonic acid . . .	8·36 ,,
,, ,, Jones' anthracite coal .	1· ,,
	85·78

H. M. L.

$= 10375$. Therefore the caloric received by the carbonic acid, $= 0{\cdot}256\,x = 2746$, and the caloric received by the steam, $= 0{\cdot}094\,x = 979$.

That is the caloric received by the nitrogen would raise its temperature $\dfrac{10434}{10{\cdot}1426 + 0{\cdot}2754} = 3735^\circ$ Fahrenheit. That of the carbonic acid and steam would be increased by the same quantity.

If the temperature of the external air be 60° and it be pumped on under a pressure of three atmospheres, its temperature deduced from the formula $\dfrac{V_1}{V_2} = \dfrac{459 + t_1}{459 + t_2}$, would be 1098°.

Then the volume of the nitrogen in the furnace, under pressure 45 lbs. per inch, and temperature $1098^\circ + 3735^\circ$ would be $10{\cdot}146 \times \dfrac{13{\cdot}1}{3} \times \dfrac{459 + 1098 + 3735}{459 + 1098} = 10{\cdot}146 \times 4{\cdot}37 \times \dfrac{5292}{1557} = 150{\cdot}4$ cubic feet.

Under the same conditions the volumes of the carbonic acid and steam would be $3{\cdot}346 \times \dfrac{8{\cdot}36}{3} \times \dfrac{5292}{1557} = 31{\cdot}53$, and $0{\cdot}3114 \times \dfrac{27{\cdot}66}{3} \times \dfrac{5292}{1557} = 9{\cdot}73$ cubic feet respectively.

Therefore the aggregate volume, under these conditions, of the nitrogen, carbonic acid, and steam in the furnace, would be $150{\cdot}4 + 31{\cdot}53 + 9{\cdot}73 = 191{\cdot}66$ cubic feet.

Now the oxygen in combination with the carbon and hydrogen being $0{\cdot}9144 \times 2{\cdot}66 + 0{\cdot}0344 \times 8 = 2{\cdot}4323 + 0{\cdot}2752 = 2{\cdot}7075$ lbs., and the atmospheric air holding it $= 2{\cdot}7075 \times \dfrac{100}{21} = 12{\cdot}89$ lbs. the volume of this air under pressure 45 lbs. per inch and temperature 1098° would be $12{\cdot}89 + \dfrac{13{\cdot}02}{3} = 55{\cdot}909$ cubic feet.

Therefore the net volume of the gases, derived from the combustion of 1 lb. of this coal, theoretically available as a mechanical force, was $191{\cdot}66 - 55{\cdot}90 = 135{\cdot}76$ cubic feet, under pressure 45 lbs. per inch, temperature 4833°.

If this body be allowed to expand, till its pressure be reduced

to 15 lbs. per inch and temperature to 60°, the volume would become $135 \cdot 76 \times 3 \times \frac{459 + 4833}{459 + 60} = 135 \cdot 76 \times 3 \times \frac{5292}{519} =$ 4153 cubic feet.

The mechanical effect due to the expansion of $\frac{1}{85 \cdot 78}$ (the volume of 1 lb. of this coal) into 4153 cubic feet, was $\left\{\frac{1728}{85 \cdot 78}\right\}^{\frac{1}{3}}$ $\times 15 \times 4153 \times 85 \cdot 78 \times \frac{2 \cdot 721}{12} = 8{,}979{,}842$ lbs. raised 1 foot.

To compare the mechanical value of these gases, with that of the steam derived from the combustion of the same quantity of coal, upon the assumption that the whole caloric developed by the combustion, was transmitted into the water, it should be mentioned, that the quantity of water, upon the above hypothesis, convertible into steam at 212° by 1 lb. of this coal, as given by Sir H. De la Bèche, was 13563 lbs.

Consequently, the weight of one cubic foot of water being 62·5 lbs., atmospheric pressure 14·75 lbs. per inch, and the volume of the steam 1700 times that of the water, the duty due was, $\frac{13563}{625} \times 14 \cdot 75 \times 1700 \times 144 = 783{,}399$ lbs. raised 1 foot.

In each case the use of condensation was supposed to be omitted.

Mr. Lefroy then proceeded to state, that he had devoted much attention to the question of the practicability of conducting the combustion of the coal, in such a manner as should render the application of the elastic forces of the gaseous products of combustion, really convenient and economical. It appeared to him, that these bodies, having nearly the same specific heats as atmospheric air, and the caloric being developed in combination with their molecules, there must be an economy in using the elasticities of these bodies, in preference to the elastic force, either of atmospheric air, or of steam, due to that portion of the caloric of these bodies which it might be possible to abstract from them, in their rapid passage through the flues, and acting through the metal plates of the vessel, containing the air, or water.

The practical difficulties which had hitherto prevented the economical use of the elastic forces of these gases, resulted from

their high temperature, and the grit, or incombustible parts of the fuel, which they carried with them from the furnace; but Mr. Lefroy thought, that in the form of apparatus which he would proceed to describe, these difficulties would be entirely overcome.

He proposed to place within the same circular boiler, but near its circumference, a number, probably four, of closed furnaces, each completely immersed in the water; they would be separately stoked, by orifices in the boiler, corresponding to each furnace, and which would be closed by plates screwed tightly down after the stoking.

Each furnace would also be separately supplied with air, and the gases generated in each, would be poured out, near the bottom of the water in the boiler, by three, or more pipes, springing from the upper part of each furnace, and each terminating in a small perforated box, through which the gases would be poured in five columns, into the water, whence it was supposed they would rise purified from all grit and with their temperature reduced.

If it were found by experiment, that this arrangement did not insure a sufficient purification of the gases, a number of wire gratings, each covered with a stratum of gravel, or sand of different degrees of fineness, could be horizontally extended through the boiler, and the gases being compelled to pass through these as they rose through the water, could be purified to any degree required.

A hollow metal ball would be placed in each of the perforated boxes, which would be forced against and completely close the extremity of each pipe, when by opening the orifices to stoke the furnace, to which it was attached, the pressure in that furnace should be reduced to that of the atmosphere.

The ash, grit, &c., which would be poured down the gas-pipes into the boiler, would sink to the lower part of the spherical bottom of the boiler, whence they would be ejected through the brine pipe.

On account of the intense heat, it would probably be found advantageous to use hollow fire-bars, through which it might be advantageous to pass the supply water into the lower part of the boiler.

If the system were worked under high-pressure, say of 30

or 40 lbs. per inch, it was supposed, that the combustion of the coal, would be so rapid and perfect, that an apparatus of comparatively small dimensions would furnish very considerable power.

Should it be found, that under the conditions of very high temperature and pressure, gases of a much more elastic nature than those he had assumed, were generated in the furnaces, Mr. Lefroy expected no inconvenience, but rather increased economy, in many respects from it, for the form of the apparatus which was proposed, appeared so simple and to be so susceptible of indefinite strength, both from diminution of dimensions, and increased thickness of the parts, that he could conceive no elasticity too great to be safely handled, in a properly proportioned apparatus of the form proposed.

Finally he would enumerate, as the principal advantages of the apparatus and power he proposed to use, over the steam furnaces at present constructed, a suppression of the funnel, or chimney, a considerable saving of fuel, and a great economy in prime cost, space occupied, and labour of attendance.

Mr. W. G. Armstrong observed, that the first question to be considered was, whether a given quantity of heat applied to vaporize water, would produce a greater, or a less expansive effect, than when it was applied to the heating of air. If an estimate was made of the quantity of heat, by degrees of temperature, the comparison would appear to be in favour of water, but when it was taken into account, that the "specific" heat of water was nearly four times greater, than that of air, and consequently, that one degree of temperature in water was equivalent to nearly four degrees of temperature in air, it was easy to show, that the actual quantity of heat consumed, in expanding air to a given volume, was less, than was necessary to produce a corresponding effect with water. On the other hand, the feed-pump of an air-engine would absorb an enormously larger proportion of power, than the feed-pump of a steam-engine; but if it were practicable, as he believed it was, to recover and use over again a large proportion of the heat applied, he conceived the balance of economy, so far as theory was concerned, would be found in favour of air. What the practical difficulties might prove to be, was another question; but he thought the system was too much in its infancy,

to enable any one to speak confidently on that point. The extraordinary size of the cylinders and pistons required in Captain Ericsson's engine, appeared to be a great difficulty, but time might develop some means of obviating that objection.

Mr. Rennie said he was present at the trials of Sir G. Cayley's engine, which had to a certain extent performed satisfactorily. It must, however, be borne in mind, that to place air on an equality with water the air must be heated to 360°, in order to double its bulk, and the chief practical difficulties arose from the destruction of the material of the heating chambers, from the direct action of the fire; this was the cause of the cessation of employment of Stirling's engine, which in its form and arrangement was a decided improvement on any of its predecessors, and in fact on any of its successors.

In 1806 a somewhat similar system had been tried, in France, by Niepce, by the ignition of an explosive powder in the cylinder. The machine had, however, never proceeded beyond a mere model.

Mr. C. W. Siemens, after sketching a diagram explanatory of the action of Ericsson's engine, stated that he had not seen the machine, but he believed the description which had been given of the arrangement (p. 327) was substantially correct. He had followed its progress with considerable interest, having himself been engaged, for a number of years, in maturing an engine, in which steam was employed in a highly heated state.

The pistons being on their bottom stroke, the air from the reservoirs was admitted below, urging the working piston upward. Being heated, in its passage through the regenerator to 400° Fahrenheit, the volume of the air was increased in the proportion of 2 to 3, and hence the reservoirs were deprived of only two-thirds the contents of a working cylinder of compressed air. An additional means of economising the supply of compressed air was, by shutting off the admission, before the upward stroke was completed; allowing it to act expansively.

The pumping cylinder had, in the mean time, discharged its contents of fresh atmospheric air into the reservoir, to make up for the supply of the working cylinder, so that the pressure of 10 lbs. per square inch was always maintained. The position of the slide-valve being then reversed, the air from beneath the

working piston was free to escape into the atmosphere, but having to pass through the regenerator, the free and sensible heat contained in it was restored to the metallic wire gauze, in the inverse order to that in which it was taken up, issuing finally at little above the temperature at which it entered from the reservoir.

The descending stroke was effected by the mere weight of the pistons. When completed, the position of the slide-valve was again altered, and the air from the reservoir entered and forced the piston upward. In its passage through the regenerator it absorbed the heat which had been deposited there, and with an additional supply from the fire, its volume was again doubled, in filling the working cylinder.

Supposing the action of the regenerator could be made perfect, so that the air left the regenerator at precisely the same temperature at which it had entered, it might seem, at first sight, that the engine would work without any expenditure of heat, beyond the mere losses from radiation, &c.

This view had indeed been maintained by Captain Ericsson and others; but upon consideration it became apparent, that there was a theoretical consumption of heat, which might be very accurately calculated, from the fact that the air entered the regenerator in a compressed state and returned through it, after expansion to atmospheric pressure had taken place. This expansion was accompanied by a diminution of temperature of some 70° or 80° Fahrenheit, which became latent and had to be replaced by the fire.

The theoretical consumption of a perfect caloric engine, amounted to only one-fourteenth part of the theoretical consumption of a Boulton and Watt condensing engine. The practical arrangement of Ericsson's engine, however, rendered the attainment of such a result impossible, for the following reasons:—

Fully two-thirds of the power of the engine must be expended in working the air-pump, independent of the resisting pressure of the atmosphere, which was equal to 3-5ths lb. the total working pressure. The consequence was, that to produce the effective displacement of the piston, for one single volume of air at its full pressure, from 7 to 8 volumes had to be cooled and heated alternately.

The working piston of Ericsson's engine had, moreover, to work air-tight in a heated cylinder, which Mr. Siemens had practically found to be a matter of great difficulty. The lubricating material would become rapidly carbonised and would fill up the meshes of the regenerator.

The extent of heating surface provided, also appeared to be too small for the quantity of heat required to be transmitted. It was understood, from good authority, that the present working cylinders of 14 feet diameter, were now being replaced by others of 16 feet, which was the greatest size the breadth of beam of the vessel would permit.

Mr. Armstrong's views required correction, owing to the evolution of heat, in compressing the air in the pump, which would produce expansion and increased resistance. A corresponding cooling effect was, moreover, produced through its expansion in the working cylinder, which would diminish the power shown by him to be obtainable. These objections would, he expected, mar the anticipated results of this interesting experiment.

Mr. Bidder thought so little was known, accurately, either of the dimensions of Ericsson's engine, or of the results obtained, that the discussion could hardly be conclusive. Still, reasoning from the data before the meeting, it appeared, that unless the regenerator enabled any given portion of heat to be utilized over and over again, it was obvious, that no theoretical advantage was obtained, in using heated air, instead of vaporized water, as a motive power, and it was incapable of being applied practically with as much convenience. This was evidenced by the enormous size of the cylinders on board the "Ericsson,"—viz., 12 feet and 14 feet diameter,—by which, however, a speed of only 6 to 7 miles per hour had been attained. As the power was as the cube of the velocity, it followed, that to obtain a velocity of 14 miles per hour, with the same vessel, there would be required cylinders of between 30 feet and 40 feet diameter. He had carefully investigated the operation of the regenerator, supposing it to be theoretically perfect, and had arrived at the conclusion, that no mechanical advantage could be attained by its use.

Mr. Spiller had also, from the data, reported by the public prints to have been furnished by Captain Ericsson himself, made a calculation of the power of the engines, and, assuming

those data to be correct, he computed the total motive force produced by the expansion of the air, to be 208 H.P., taking 33,000 lbs. raised 1 foot per minute, as the standard of the horse-power;—that whether in a steam, or an air-engine, friction and waste were inevitable, and if only a sufficient amount was deducted, for these causes of loss, it would be found, that many of the marine-engines were producing power more economically, than the heated air engines in question. He also remarked, that although any given amount of heat, acting on air, might produce more motive force, than the same amount employed to produce motive force by steam, still he believed, that in consequence of the very low pressure of air, except at so high a temperature as to be destructive of the necessary perfection of the working parts of every engine, steam would be found more economical than air, as an agent for the production of motive power, and hence however laudable the attempt might be, he could see but little prospect of success in this trial for substituting air for steam.

As to the regenerator, which had excited so much interest,—that some economy might be produced by such an apparatus, there could be no reasonable doubt, notwithstanding what had been said of the impossibility of employing heat a second time, or "over again." The metallic wire acted as a reservoir, to embody, or take up a portion of the heat in the outgoing air; which heat, so embodied, was given out to the incoming air, for the succeeding stroke,—a principle carried into effect in every non-condensing engine, where the eduction-steam was employed to heat the feed-water, before it entered the boiler, and also by Messrs. Maudslay and Field, in ocean steamers, where the brine pumps, &c., were so arranged, as to communicate a very large portion of the heat of the outgoing water, to that drawn in to feed the boilers.

Dr. Faraday said, that twenty years ago he had directed his attention to this question, and from theoretical views, he had been induced to hope for the successful employment of heated air as a motive power; but even then he saw enough to discourage his sanguine expectation, and he had, with some diffidence, ventured to express his conviction of the almost unconquerable practical difficulties surrounding the case, and of the fallacy of the presumed advantages of the regenerator. He

still retained his doubts as to the success of the innovation and feared the eventual results, even of Captain Ericsson's spirited and ingenious efforts.

Mr. Brunel, V.P., agreed in considering the regenerator to be a mystification, and the difficulty of the matter arose from its plausibility. It was extremely difficult to disprove that which did not exist at all. He believed the stated gain of power, from the action of the regenerator, to be mere assumption, and he was inclined to regard it just as he would any attempt to produce perpetual motion; still he admitted the difficulty of exposing the fallacy, as he contended it to be, when it was asserted, that the power derived from the expansion of air by heat, could be used effectively, and then be recovered and used again.

He could not gather, from any of the statements, how power was actually obtained; and he could only arrive at the conviction, that if there was any development of power, in lending heat to the metallic webs and borrowing it again, the natural consequence must be, that after a time there might be such an accumulation of borrowed heat, as would enable the machine to work, without any fire under the heating vessels. It was scarcely worth while to expend time in the refutation of such a fallacy. The same kind of error had been fallen into, with respect to the hot water from the condenser of a steam-engine; but in that case it was clear, that the advantage arose, not from recovering heat which had been previously used, but by obtaining some that had not been used before, and which would otherwise have been wasted.

He was of opinion, that Stirling's engine was not only a prior introduction, but that it was a better machine than Ericsson's; still he thought that neither of them could be advantageously compared with a steam-engine.

Mr. Hawksley believed, that the machine involved a mechanical fallacy, as the regenerator produced no mechanical effect whatever. It might be granted, that the regenerator of Ericsson's engine received and redelivered the heat in the manner described, and that when the working piston was descending, the heat was deposited, and when ascending, the heat was restored; but that operation could only result as a consequence of the motion of the piston and not as a cause of its motion -- hence no mechanical effort was made. This result

was easily shown by assuming the contents of the pump to be 1, and the contents of the working cylinder to be 2. If the working piston was at the bottom of the cylinder, and in equilibrio with the external atmosphere, as regarded the pressure on a unit of surface, and then began to move and the air to be heated, in its passage through the regenerator, from 32° to a temperature of 512°, so as to double its volume, the lower piston would constantly produce a vacuity, so to speak, of 2, to be constantly fed by a supply of 1, from the pump, expanded into 2 by the increase of temperature,—consequently the piston, at every instant of its motion, remained in equilibrio with the external atmosphere, and no mechanical effect could result. Still in Ericsson's engine a mechanical effect had been produced; but then this mechanical effect was no greater than would be produced without the aid of the regenerator, by the simple action of the furnace itself, and not so economically as by the use of steam.

Captain Fitzroy, R.N., said it appeared, that after imparting motion to the piston, the heated air, in passing through the regenerator, gave out to the metallic web 520 parts out of 570 parts of heat it contained, and that a part of that heat was taken up again by the next supply of cold air on entering; therefore, the mystery consisted in the action of the regenerator, by which the same caloric, husbanded and given out again, could, by a small addition of heat, continue to impart motion to the pistons. The chief argument against the imputed fallacy, was the fact of the ship "Ericsson" having actually been propelled at a given speed through the water. The relative economy of the system, compared with steam, was entirely another question.

Mr. Bidder begged it might be understood, that in his remarks he had assumed the regenerator to have taken nearly all the heat, but he contended that when so taken up, it was not of any practical utility; in fact, this was, to some extent, shown by the result obtained in the "Ericsson" ship; for, with so fine a model, even a small engine and a much less consumption of fuel would have produced a greater speed.

Mr. Brunel, V.P., had also assumed the regenerator to be perfect. He believed that such a mass of wire-gauze would take up the heat perfectly, but he could not admit the soundness

of the reasoning, as to the assumed gain of power from the regenerator.

Mr. F. BRAITHWAITE recalled the circumstances attending the first trials of Ericsson's caloric engine, in England: there was not any regenerator, but there was a separate vessel for heating the air, and a refrigerator for cooling it. There was not any difficulty in obtaining power from the expanded air, but there was great difficulty in finding any lubricator, that would enable the pistons to work for any length of time continuously, as the high temperature carbonized all the fatty matters that were tried. The caloric-engine was tested by pumping water, but the results were not equal to those of the steam-engine, in a commercial point of view.

He did not consider the regenerator to be necessary for the engine; it certainly was not a source of power, and it was problematical whether it was a means of economy.

Mr. W. G. ARMSTRONG said his view of the action of the regenerator was, that it retained a portion of the heat, which would otherwise have been lost; whether that heat was practically as beneficial, in the subsequent working of the engine, as had been assumed by the advocates of the system, did not yet appear to be fully proved. He thought, that for the credit of the Institution, the question should be more carefully considered.

Mr. RENDEL,—PRESIDENT,—would not have the meeting arrive at a hasty, or erroneous conclusion, on the question of this engine; and he, therefore, suggested, that Mr. Siemens should draw up a paper on the subject, and that the Members should collect, for a future meeting, all the information within their reach, in order to the calm and deliberate discussion of the question.

February 22nd, 1853.

JAMES MEADOWS RENDEL, President,
in the Chair.

THE discussion upon the Paper No. 886.—"On the use of Heated Air as a Motive Power," by Mr. B. CHEVERTON, being renewed, was extended to such a length as to preclude the reading of any other communication.

March 1st, 1853.

JAMES MEADOWS RENDEL, President, in the Chair.

THE following candidates were balloted for and duly elected:— James Barton, as a Member; James Collins, Robert Ogilvie, Arthur Wightman, and George Wilkie, as Associates.

No. 889.—"On the increased Strength of Cast Iron, produced by the use of improved Coke." By FREDERICK CRACE CALVERT; with a Series of Experiments, by WILLIAM FAIRBAIRN, M. Inst. C.E.

IT must be well known to all who are acquainted with the manufacture of iron, that in the ratio of the rapidity of its production, is its deterioration in quality, and it is one of the objects of the present paper to explain the causes of this action.

When charcoal is employed in the blast furnace, the produce is about 2 tons of iron in 24 hours, whilst by the use of coke, or coal and hot blast, from 20 to 30 tons can be smelted in the same time; and it may be doubted, whether the iron-masters are not more inclined to regard the quantity, than by strict attention to the best methods of production, or to the proportions of the materials employed, to improve the quality of the iron produced. Indeed, complaints have been lately made, by the consumers, as to the very inferior quality of the iron now supplied to them, compared with that of former years, and, unless some change be made, it is to be feared, that the trade may pass from their hands into the workshops of the Continent.

The Author's principal object, in this paper, is to direct the attention of iron-masters to the importance of conducting the different workings of a blast furnace, with more attention to the chemical action, which, he believes, is not at present sufficiently attended to.

In the first place, especial attention is invited to the fact, that ores, widely differing in their relative value and chemical composition, are frequently used in the furnaces, with

the same proportions of lime-stone, cinder, and fuel. Instances have occurred, for example, where a siliceous ore has been used for some hours successively, and then at once replaced by an aluminous, or calcareous iron-stone, without any change being made in the proportions of lime-stone, or coal, which the different qualities of these ores evidently required.

The nature and quantity of flux employed, should vary according to the peculiar chemical composition of the ores, and further, the proportion of fuel, necessary to fuse a vitreous, or calcareous cinder, varies in the same degree, inasmuch as these respectively demand very different amounts of caloric to reduce and liquify them. Hence, the required quality of metal can never be produced with certainty, unless the differing qualities of the iron-stone have been previously examined, and the relative proportions of flux and fuel regulated accordingly.

If due care were observed in working, so as to maintain a proper admixture of the materials, identical results would almost invariably be obtained. When the furnace-men wish to produce a softer metal, they are enabled to do so, by adding more fuel for the same weight of ore and flux, and although this practice succeeds, when the men are careful, and are attentive in using the same quality of ore and flux, still it seldom gives a positive result, owing to the causes above enumerated.

Some iron-smelters assign, as a reason for the addition of from one to three cwt. of coal, or coke, to the quantity usually employed in each charge, that by so doing, they are adding to the quantity of carbon, which they state to be necessary to produce in the furnace No. 1 instead of No. 3, or No. 4 cast iron. Now, it must be borne in mind, that the difference between the quantity of carbon contained in No. 1 and No. 4 iron is very trifling, even if it can be discovered; and it has been demonstrated, that the chief difference between the two kinds of iron is due, in a great measure, to their molecular condition. In fact, if No. 1 iron be melted, and cooled rapidly, it will assume the appearance of No. 3, or even of No. 4 iron. But even, admitting that there is an addition of carbon, and that the excess amounts to even 1 per cent., there would only be 2 cwt. more carbon in 10 tons of No. 1 iron, than there would be found in the same quantity of No. 4 iron; whilst the smelter may have

added, on the top of the blast furnace, 3 or 4 tons of coal, or coke to produce this result.

These facts would appear to demonstrate the correctness of the opinions here expressed, that the additional fuel, used in producing No. 1 iron, is principally required to melt the nearly infusible flux which accompanies the production of that quality of metal.

These remarks, respecting the want of care and attention paid to the chemical composition of the ores which are smelted in blast-furnaces, are equally applicable to the quality of the flux used. Thus, in Scotland, limestones, differing as much as 20 or 30 per cent. in value, are employed in the same proportion for each charge, and instances have occurred where their value has varied 66 per cent. This difference arises principally from their often containing a large proportion of silica, which will render useless an equal weight of lime, when undergoing fusion.

From trials, made on a large scale, for better fluxing the silica contained in the ore, a method was devised which is now adopted, and through which it has been found, that by employing a proper proportion of lime, the furnace works better, and the iron contains less silicium: consequently it is less brittle, and of greater tenacity.

Indeed, it would appear, that the relative proportion of silicium in iron has a great influence on the quality of the metal, and deserves more serious attention than iron-masters have hitherto paid to it.

The following analysis will give an idea of the various quantities per cent. of silicium existing in cast iron:—

White Crude Iron.	Monkland.	Coltness.	Eglinton.	Dalmillington.
0·18	1·53	2·69	3·12	4·42

Another exceedingly injurious practice, in the manufacture of iron, is the addition, in the blast furnace, of slag from the puddling furnaces, or the refinery, as the silicate of iron, of which the slag is principally composed, contains large quantities of sulphur and phosphorus, as is shown by the following analysis of puddling-furnace slag, or scoria, at Ebbw-Vale:—

Peroxide of iron	7·14
Protoxide of iron	63·34
Silicic acid	23·20
Phosphorus	3·72
Sulphur	2·60
Lime, magnesia, Alumina and manganese	Traces.
Total	100·00

The manner in which the slag acts injuriously appears to be, that when it is used in the blast furnace, in quantities varying from 28 lbs. to 3, or 4 cwts. to each charge, or round, it agglomerates into one mass, and, gradually descending, is melted, before it has reached a depth of 20 feet; it then trickles through the materials in the furnace, and if it meets with lime, it is fluxed,—but if not, it travels on, until it comes into contact with the iron, as formed near the tuyere, and thus becomes incorporated with it, rendering it impure, brittle, and of inferior quality.

The effect of the use of such slag was greatly modified at Ebbw-Vale, by breaking it into small pieces, of one inch cube and under, and mixing these lumps intimately with broken quicklime, previous to their introduction into the furnace, so that when they arrived at a melting heat in the furnace, these pieces of slag came into immediate contact with the quick-lime, which was thus enabled to act upon the silica, liberating the oxide of iron.

Before passing to the fuel, the consideration of which forms the principal object of this paper, it is necessary to observe, that when hot blast is used, more care should be taken to maintain a regular temperature in the hot-blast apparatus, particularly at night, when the master, or manager is not present, to exercise control over the workmen. Therefore, great advantage would result from the more general employment of a simple kind of pyrometer, similar to that used at Coltness. It consists of a rod of iron, having one of its ends fixed in the wall, and after traversing the air-heating furnace, acting with the other end, upon a lever connected with a needle, so as to indicate on a dial, by its expansion, the temperature of the furnace. In addition to this, if the other end of the needle were lengthened, so as to move a smaller needle, traversing in a contrary direc-

tion, and so enclosed in a box, as to be out of the reach of the workman, it could be made to indicate the maximum and minimum heat of the furnace, during any given period.

A better mode of enregistering the speed of the engine which furnishes the blast, would be advantageous, and it would be well to employ the combustion of the gases from the top of the blast furnace, as is generally done on the Continent, and as is also successfully applied at the Coltness iron-works, in roasting Clay-band iron ore, and in generating the steam power required to drive the blast engines, and at the Ebbw-Vale works, not only for the last-named purpose, but also as fuel for the air-heating apparatus.

It is now necessary to direct attention to the injurious action which impure fuel has on the quality of the iron, and principally that fuel which contains sulphur; for in the ratio of the quantity of sulphur existing in the coal, or coke, will a relative proportion find its way into the cast iron, and render it "red short." It is, therefore, highly advantageous, that the fuel should be freed from sulphur, before it is employed in the blast furnace, or before it can possibly impart to the cast iron the sulphur it contains.

The presence of either sulphur, phosphorus, arsenic, or silicium is always injurious, and it is chiefly owing to these heterogeneous substances, that the English iron is inferior to the Swedish; and although this fact is generally known, still it is submitted, that it has never been so clearly demonstrated as in the examples now laid before the Institution; for these examples are the first which have been obtained, in which the influence of sulphur, or phosphorus can be duly appreciated, as the same iron is seen with, or without these injurious substances; and the marked difference existing between the Monkland malleable iron, made from cast iron, prepared with coal, as compared with the malleable iron obtained with coal and the improved process, is shown. In fact, this last iron, from which the sulphur has been removed, is found, on comparing it with some best French and German malleable irons, made with wood-charcoal, to be quite equal to them in every respect.

These improvements which have been effected practically, at a very small cost, are carried out in the following manner:—

If the blast furnace is worked entirely with coal, chloride of

sodium is added with it, as it is introduced into the blast furnace; or a better result is obtained by working the furnace with coal and coke, the latter having been prepared, by mixing with the coals, either previously to, or whilst they are being introduced into the coke oven, a proportion of chloride of sodium, varying from one-half to 3 per cent. During the process of coking, a chemical action takes place, and the coke is deprived of a great portion of the sulphur,—care being taken, that in its preparation an excess of the chloride should be used, in order to act on the sulphur of the coal and of the ore, if, from its quality, it should be found to contain any. Thus, it follows, that if only coke was employed in the blast furnace, as is generally the case in Staffordshire, the improvement would be still more manifest.

This opinion is entertained from the results obtained, in conjunction with Mr. Fairbairn, on iron melted in the same cupola with purified coke, as compared with the products from the ordinary coke made from the same coal, but without the purifying process.

The coke prepared by the process alluded to, does not emit any sulphurous fumes, like the ordinary coke, when taken out of the ovens, nor does it, when extinguished with water, give off the unpleasant odour of sulphuretted hydrogen; and no sulphurous acid gas is liberated, during the operation of melting iron, nor when used in locomotives. On the Blackburn division, of the Yorkshire and Lancashire Railway, the coke, so purified, is used daily in all the locomotives, at an additional cost of one penny per ton.

The action of the chloride of sodium is as follows: when coal is first subjected to heat, in a coke oven, the bisulphuret of iron is decomposed into sulphur, which distils, or is converted into sulphurous acid and protosulphuret of iron, which remain in the coke. The latter is acted upon by the chloride of sodium, producing chloride of iron and protosulphuret of sodium. Here, a second chemical reaction ensues, the protochloride of iron is decomposed into a subperchloride of iron-and the chlorine gas, thus liberated, reacts on the sulphuret of sodium, giving rise to chloride of sodium and to chloride of sulphur, which is disengaged, so that the prepared coke contains less sulphur than the ordinary coke. But admitting, even, that

a small portion remains, it will be in the state of sulphuret of sodium, which will not yield any of its sulphur, during combustion, but will pass into the cinders of the blast-furnace, or of the cupola and into the ashes of the fire-box of the locomotive, and thus the injurious effect of the sulphur upon the copper of the fire-box, on the brass tubes of the boiler, and on the iron bars, generally, is prevented.

Nor are these the only benefits, arising from this process of preventing the combustion of the sulphur, for it must be remembered, that the sulphurous acid fumes are carried over the tops of the carriages and on to the tarpaulings of the goods trains, and are there converted into sulphuric acid, which must contribute, in no small degree, to the present rapid decay of the material.

There is an easy experiment, which will leave no doubt of the complete decomposition of the protosulphuret of iron being effected by the agency of chloride of sodium; it is, by calcining, for two hours, in a porcelain crucible, at an intense red heat, a mixture made with one equivalent of the above substances, and two equivalents of chloride of sodium, and the result will be, that there will be found, as a residuum, subperchloride of iron and no trace of sulphuret of iron. This result must appear worthy of consideration, for if the chloride of sodium decomposes the sulphuret of iron in the crucible, it must have the same effect upon the sulphuret of iron in the coal, whilst it is being transformed into coke, or on the sulphuret of iron which exists in the coal, when used for smelting iron, or even, when it is found in the cast iron, while being fused in the blast-furnace, or cupola.

The effect is also satisfactorily proved, by the analyses of the Dalmillington iron, from which a large quantity of sulphur and phosphorus had been removed, by the application of the chloride of sodium in the blast-furnaces, worked entirely with coals.

SULPHUR in DALMILLINGTON IRON.

	Without the Process.	With the Process.	
	Per Cent.	Per Cent.	
	0·95	0·218	
	..	0·208	

STRENGTH of 1 Inch square BARS;—4 feet 6 inches between the Bearings.

Without the Process.	With the Process.
487	556
456	525
487	544
470	562
..	569

Similar results have been obtained at the Monkland furnaces, worked entirely with coals.

SULPHUR in MONKLAND IRON.

Without the Process.	With the Process.
Per Cent.	Per Cent.
0·39	0·15

STRENGTH of BARS 1 Inch square;—4 feet 6 inches between the Bearings.

Without the Process.	With the Process.
579	627
576	655

Special attention is directed, to the analyses of the Eglinton iron, which has been employed, in a series of experiments conducted by Mr. Fairbairn personally, in order to ascertain what improvement could be effected in cast iron, when melted in a cupola, with coke prepared by the improved process, as compared with iron, so melted with coke from the same coal, but made in the ordinary way.

SULPHUR in EGLINTON IRON.

Eglinton Pig Iron.	Melted in the Cupola with ordinary Coke.	Melted in the Cupola with purified Coke.
Per Cent.	Per Cent.	Per Cent.
0·336	0·281	0·191

The above results clearly show, that the iron has lost a great portion of the sulphur which it contained, previously to its

being subjected to the action of the purified coke; and as to the increase of strength, Mr. Fairbairn's experiments have shown, that the remarkable improvement effected in the cast iron by melting, is to be ascribed to the use of purified coke.

Much depends, not only on the quality but the quantity of fuel used in the melting process, and it would appear, that a useless, if not a destructive expenditure of coke, is frequently the result of the management, or rather the mismanagement of the furnaces in Lancashire and other parts of the North where coal is cheap; indeed, if the same economy and care were observed in those districts, as is exercised in London and in the South, where fuel is expensive, a much cheaper and better description of iron might be produced.

In corroboration of these remarks, the following carefully conducted experiments, made by Mr. Fairbairn, upon iron melted in the cupola by means of the purified coke, accompanied with a comparison of the same iron, melted by the ordinary coke, are laid before the Institution.

"Experiments on the Strength of Cast Iron smelted with Purified Coke," by WILLIAM FAIRBAIRN, M. Inst. C.E.

Since the introduction of the use of hot blast and the great economy which that process has effected, in the smelting of iron ores, great uncertainty has been experienced, as to the quality of the metal produced. It is not intended to affirm, that the use of heated blast *per se* does certainly deteriorate the quality of the iron so produced; but, there can be no hesitation in stating, that it places in the hands of the iron-maker great facilities for the reduction of inferior ores, and where coal is used instead of coke, a great proportion of sulphur, which is not vaporized, or oxidized during the process, combines with the iron and not only injuriously affects the cohesive power of its crystalline structure, but seriously injures the density and the formation of its molecular construction. It is correctly observed by Mr. Crace Calvert, it is scarcely possible to conceive "the injurious action which impure fuel has on the quality of the iron, and principally that fuel which contains sulphur, for in the ratio to the quantity of sulphur existing in

the coal, or coke, so will a relative proportion find its way into the cast-iron and render it red short."

Under all the circumstances, it has been repeatedly proved, that the presence of sulphur and phosphorus, either in the blast furnace, or the cupola, is exceedingly deleterious, and produces the most injurious effects upon the tenacity of the crystalline products. Any process, therefore, by which these substances can be removed, or their combination be prevented, will greatly enhance the value of the iron, and afford much greater certainty, as regards uniformity of strength and all those properties which constitute increased powers of resistance, and increased facilities for its application to the varied requirements of the useful arts.

For some years past, great difficulty has been experienced, in obtaining sound castings, from a quality of iron which has all the appearance of being perfectly good; but which, on being fused, exhibits a combination of slag, or scoria and earthy matter, which enters into the moulds and produces large masses of unsound metal, evidently mixed with other substances, entirely destroying the uniformity of its crystalline texture, and producing a spongy porous casting, which in some cases crumbles into dust. Some irons of this kind are not only destructive to the objects for which they are intended, but seriously affect the art as well as the profits of the founder, by the number of 'wasters' that are produced.

To determine the merits of any particular process, when compared with others, it is essential to establish some known principle, by which the products of that process can be fairly and honestly tested. To arrive at correct results in the present case, it is necessary to ascertain in what consists the difference between the iron produced from one description of coke, as compared with the results of the use of another description; and also to show wherein consists the improvement, or deterioration thus effected; the flux and other conditions of the furnace being the same. For these objects it is only necessary to direct attention to the following summary of results, which at once determines the advantages peculiar to the new process and the superior quality of the iron, melted with the improved coke, as regards its increase of strength.

Taking the mean of the whole experiments the following conclusions are arrived at:

	lbs.
The mean breaking weight of the bars per square inch, melted with the purified coke, is	515·5
The mean breaking weight of the bars per square inch, of the same iron, melted with the ordinary coke	427·0
or	88·5

in favour of the castings produced from the improved coke, being in the ratio of 515 : 427, or nearly as 5 : 4.

Taking the mean of all the experiments, the power of resisting impact, would appear to be in the ratio of 798·5 : 755·5 or 43·0 lbs. in favour of the bars melted from the ordinary coke. The bars from the common coke exhibiting less rigidity in the crystalline structure, and a greater amount of flexure, when submitted to a transverse strain.

The results thus obtained from identically the same iron, melted, as nearly as possible, under the same circumstances, but with coke of different degrees of purity, are not only satisfactory as respects the improvement effected; but the comparatively small cost at which the purifying of the coke can be effected is a point of importance, and is a main reason for bringing the subject under the notice of the Institution.

A short description of the apparatus by which the results were obtained may be useful, as it exhibits the advantages of this method of experimenting, by the substitution of actual weights for the lever, which cannot in every case be depended upon.

The apparatus consists of a strong frame, with a wheel and screw fixed in the centre of the cross beam, from which is suspended the scale, with the load intended to break the bar to be experimented on, which latter rests on two cast-iron brackets screwed on the standards, at the exact distance of 4 feet 6 inches asunder.

Having fixed the bar, the weight of the scale is gently lowered upon the middle of the bar, and having ascertained the

deflection by a graduated scale of inches and parts, inserted between the bar and the gauge, the whole weight is then raised clear of the bar by the screw, when the set, or defect of elasticity, is determined. In this way the bars are successively loaded with weights, varying from 56 lbs. to 28 lbs. and 14 lbs. at a time, until fracture ensues.

EXPERIMENTS.

To determine the relative strength of Bars of cast-iron, 1 inch square, smelted by Mr. Calvert's purified and by common coke; the distance between the supports being in all cases 4 feet 6 inches.

Experiment I,—Bar No. 1.

Cast from Eglinton, No. 4 iron, fused by purified coke. Depth of Bar •97 inch; width •96 inch,—4 feet 6 inches between the supports.

No. of Experiment.	Weight laid on in lbs.	Deflection in Inches.	Deflection-load removed.	REMARKS.
Scale.				
1	31	+		
2	87	•19		
3	143	•36		
4	199	•52		
5	255	•68		
6	311	•75 •88	••	Weight removed and again restored, without any apparent defect of elasticity; deflection increased to •88.
7	367	1•08		
8	423	1•28 1•35	••	Weight removed and again restored.
9	437	1•38		
10	451	1•43	••	Apparently no change in its elasticity.
11	465	1•49		
12	479	1•53		
13	493	••	••	Broke in the middle.
		Ultimate Deflection =1•57		

Results reduced to bars 1 inch square.

	b Breaking-weight in lbs.	d Ultimate Deflection in Inches.	Product $b \times d$ or Power of resisting Impact.
Mean Sectional Area •965 inch No. 1 Bar. 4 feet 6 inches between the supports.	511	1•62	828•8

The appearance of the fracture of this iron was of a clear grey colour, remarkable in its uniformity of texture and in its crystalline structure.

EXPERIMENT II,—Bar No. 2.

Cast from Eglinton, No. 4 hot-blast iron, fused by the purified coke. Depth of Bar 1·04 inch—width ·95 inch,—4 feet 6 inches between the supports.

No. of Experiment.	Weight laid on in lbs.	Deflection in Inches.	Deflection-load removed.	REMARKS.
Scale.				
1	31	+		
2	87	·05		
3	143	·20		
4	199	·33		
5	255	·48		
6	311	·65	..	No change in elasticity.
7	367	·77		
8	423	·98		
9	451	1·06	..	No change.
10	465	1·10		
11	472	1·12		
12	479	1·14		
13	484	1·15		
14	487	1·16		
15	490	1·17		
16	495	1·18		
17	499	1·20		
18	504	1·22		
19	509	1·23		
20	513	1·24		
21	518	1·26	·660	
22	523	1·27		
23	528	1·30		
24	532	1·32		
25	537	1·33		
26	541	1·35		
27	546	1·37	·175	
28	551	1·40		
29	558	..	..	Broke near the middle of the bar.
		Ultimate Deflection =1·47		

RESULTS reduced to bars 1 inch square.

	b Breaking-weight in lbs.	d Ultimate Deflection in Inches.	Product b × d or Power of resisting Impact.
No. 2 Bar. 4 feet 6 inches between the Supports.	560	1·47	823·20

The metal appeared to have run exceedingly close, and exhibited a compact granulated structure, with a light-grey colour.

EXPERIMENT III,—Bar No. 3.

Cast from Eglinton, No. 4 hot-blast iron, fused by the purified coke. Depth of Bar, 1·32 inch; width ·972 inch,—4 feet 6 inches between the supports.

No. of Experiment.	Weight laid on in lbs.	Deflection in Inches.	Deflection-load removed.	REMARKS.
Scale.				
1	31	+		
2	87	·01		
3	143	·17		
4	199	·40		
5	255	·57		
6	311	·72		
7	367	·87 ·87	..	After weight had been taken off and restored.
8	423	1·02		
9	451	1·13		
10	465	1·16		
11	472	1·19		
12	479	1·20		
13	484	1·23		
14	487	1·24		
15	490	1·25		
16	495	1·27		
17	500	1·275		
18	505	1·29		
19	509	1·30		
20	513	1·32		
21	518	1·34		
22	523	1·36 1·37	·05	After weight had been taken off and restored.
23	530	1·37		
24	537	1·41		
25	544	1·43		
26	551	1.46		
27	558	1·46		
28	565	..	..	Broken a short distance from the middle of the bar.
		Ultimate Deflection =1·47		

RESULTS reduced to bars 1 inch square.

a	b Breaking-weight in lbs.	d Ultimate Deflection in Inches.	Product b × d or Power of resisting Impact.
No. 3 Bar. 4 feet 6 inches.	563	1·47	827·61

This iron presented all the characteristics of that in the last experiment; of great density, and exceedingly compact in its crystalline appearance; colour the same as No. 2.

The result of the experiments on No. 2 and No. 3 bars indicated iron of a high order as to strength, and which might be considered equal to the strongest cold-blast.

EXPERIMENT IV,—Bar No. 4.

Cast from Eglinton, No. 4 hot-blast iron, fused by ordinary coke. Depth of Bar 1·015 inch; width, ·96 inch,—4 feet 6 inches between the supports.

No. of Experiment.	Weight laid on in lbs.	Deflection in Inches.	Deflection—load removed.	REMARKS.
Scale.				
1	31	+		
2	87	·26		
3	143	·43		
4	199	·66		
5	255	·97		
6	311	1·27 / 1·29	e·046	Weight removed, increase of deflection ·02.
7	367	1·67		
8	395	1·83	·17	
9	409	1·96		
10	423	..	..	Broke after sustaining the weight about three minutes.
		Ultimate Deflection = 2·02		

RESULTS reduced to 1 inch square.

No. 4 Bar. — 4 feet 6 inches between the Supports.	*b* Breaking-weight in lbs.	*d* Ultimate Deflection in Inches.	Product *b* × *d* or Power of resisting Impact.
	428	2·04	873·12

Here there was a comparatively weak iron, with increased deflexion, and superior in its power to resist impact. It was much more porous in the fracture, than the iron melted by the purified coke, and exhibited a rim of a closely granulated texture round the outer edge of the bar; the colour was dull grey, with an appearance of minute particles of sand in combination with the iron.

EXPERIMENT V,—Bar No. 5.

Cast from Eglinton, No. 4 hot-blast iron, fused by ordinary coke. Depth of Bar 1·01 inch; width ·96 inch;—4 feet 6 inches between the supports.

No. of Experiment.	Weight laid on in lbs.	Deflection in Inches.	Deflection-load removed.	REMARKS.
Scale.				
1	31	+		
2	87	·34		
3	143	·55		
4	199	·87		
5	255	1·16		
6	311	{ 1·57 1·59 }	·17	Weight removed.
7	367	..	..	Broke in the middle.
		Ultimate Deflection =1·89		

RESULTS reduced to 1 Inch square.

	b Breaking-weight in lbs.	d Ultimate Deflection in Inches.	Product b × d or Power of resisting Impact.
No. 5 Bar. — 4 feet 6 inches between the Supports.	380	1·946	739·12

The colour of the fracture was the same as in Experiment IV. On comparing the results of the two Experiments, IV. and V., it will be observed, that a considerable difference exists between the bars, both as regards their respective powers of resistance to a transverse strain, and their power of resisting impact. These discrepancies often appear in castings, and not unfrequently perplex the Engineer, as well as the workman, to account for the variable increase, or diminution of power which occur in the various castings from the same melting; the rate of cooling, the difference of temperature in the metal, when the moulds are run, as well as other causes, may, however, be considered to lead to the variable condition of the solidified mass.

EXPERIMENT VI.—Bar No. 6.

Cast from Eglinton, No. 4 hot-blast iron fused by ordinary coke. Depth of bar, 1·00 inch; width, ·96 inch,—4 feet 6 inches between the supports.

No. of Experiment.	Weight laid on in lbs.	Deflection in Inches.	Deflection-load removed.	REMARKS.
Scale.				
1	31	+		
2	87	·22		
3	143	·43		
4	199	·70		
5	255	1·00		
6	311	{ 1·38 1·40 }	·06	{Weight removed and again restored; increased deflection, ·02.
7	339	1·55		
8	343	1·68	·18	
9	377	1·80		
10	391	1·90	·26	
11	415	2·00		
12	422	..	..	Broke near the centre of the bar.
		Ultimate Deflection =2·01		

RESULTS reduced to bars 1 inch square.

	b Breaking-weight in lbs.	d Ultimate Deflection in Inches.	Product of $b \times d$ or Power of resisting.
No. 6 Bar — 4 feet 6 inches between the Supports.	430	2·04	877·2

This bar had all the characteristics of that in Experiment IV. It exhibited nearly the same amount of strength and deflection, and might, in other respects, be considered a fair average quality of iron.

The colour of the fracture appeared more luminous than No. 4 and 5 bars, but was not so sparkling as those fused by the purified coke.

EXPERIMENT VII,—Bar No. 7.

Cast from Eglinton, No. 4 hot-blast iron fused by ordinary coke. Depth of bar, 1·09 inch; width, ·972 inch;—4 feet 6 inches between the supports.

No. of Experiment.	Weight laid on in lbs.	Deflection in Inches.	Deflection-load removed.	REMARKS.
Scale.				
1	31	+		
2	87	·10		
3	143	·16		
4	199	·37		
5	255	·52		
6	311	·68		
7	367	·84 / ·86	..	After weight had been removed and again restored.
8	423	1·02		
9	451	1·12		
10	465	1·20		
11	479	1·23 / 1·24	..	,, ,, ,,
12	486	1·26		
13	493	1·29		
14	493	1·31		
15	503	1·33		
16	508	1·35		
17	513	..	..	This bar was rather defective, being blown at one place.
		Ultimate Deflection =1·36		

RESULTS reduced to bars 1 inch square.

	b Breaking-weight in lbs.	*d* Ultimate Deflection in Inches.	Product of $b \times d$ or Power of resisting Impact.
No. 7 Bar. 4 feet 6 inches between the Supports.	497	1·12	651·07

The ultimate strength, deflection, and power of resisting impact was not so great in this iron as in Nos. 1, 2, and 3 bars, which were cast from the same coke, and although superior in its resistance to a transverse strain, it was nevertheless deficient in its power to resist impact. In colour it was a lightish grey, with a sharp hard exterior, and a crystalline structure.

EXPERIMENT VIII,—Bar No. 8.

Cast from Eglinton, No. 4 hot-blast iron, fused by ordinary coke. Depth of Bar, 1·09 inch; width, ·93 inch;—4 feet 6 inches between the supports.

No. of Experiment.	Weight laid on in lbs.	Deflection in Inches.	Deflection-load removed.	REMARKS.
Scale.		s		
1	31	+		
2	87	·10		
3	143	·23		
4	199	·36		
5	255	·44		
6	311	·72		
7	367	·93	..	No change.
8	423	1·01		
9	451	1·20		
10	465	1·26		
11	479	{ 1·33 1·34 }	·062	Weight again restored.
12	486	1·36		
13	493	1·38	·12	
14	498	1·40		
15	503	1·42		
16	508	1·43	·18	
17	513	1·44	..	Slightly.
18	518	Broke.	..	Another defective bar, same as last.
		Ultimate Deflection =1·45		

RESULTS reduced to bars 1 inch square.

No. 8 Bar. — 4 feet 6 inches between the Supports.	b Breaking-weight in lbs.	d Ultimate Deflection in Inches.	Product of $b \times d$ or Power of resisting Impact.
	511	1·432	730·73

There appeared to be no particular difference in the appearance of this bar and the last (No. 7). It exhibited the same granulated fracture, and was of as near as possible equal, if not greater density. It was a rather stronger iron than No. 7, and presented increased power of resistance to impact.

EXPERIMENT IX,—Bar No. 9.

Cast from Eglinton, No. 4 hot-blast iron, fused by purified coke. Depth of Bar, 1·03 inch; width, ·968 inch;—4 feet 6 inches between the supports.

No. of Experiment.	Weight laid on in lbs.	Deflection in Inches.	Deflection-load removed.	REMARKS.
Scale.				
1	31	+		
2	87	·20		
3	143	·34		
4	199	·53		
5	255	·73		
6	311	·94		
7	367	1·16 1·18	·061	Loss of elasticity.
8	423	1·40	·124	This bar also was slightly defective.
9	451	Broke.		
		Ultimate Deflection = 1·49		

RESULTS reduced to bars 1 inch square.

No. 9 Bar. — 4 feet 6 inches between the Supports.	b Breaking-weight in lbs.	d Ultimate Deflection in Inches.	Product of $b \times d$ or Power of resisting Impact.
	451	1·49	671·99

No. 9 bar broke 4½ inches from the centre, having a slight flaw in that part of the casting; it would not, however, have borne many more lbs., as the defect was only just perceptible. The appearance of the fracture was the same as before.

EXPERIMENT X,—Bar No. 10.

Cast from Eglinton, No. 4 hot-blast iron, fused by ordinary coke. Depth of Bar, 1·04 inch; width, ·941 inch;—4 feet 6 inches between the supports.

No. of Experiment.	Weight laid on in lbs.	Deflection in Inches.	Deflection-load removed.	REMARKS.
Scale.				
1	31	+		
2	87	·20		
3	143	·37		
4	199	·55		
5	255	·76		
6	311	1·00	·12	
7	367	1·28	··	No change; weight again restored.
8	423	1·54	·18	
9	451	Broke.		Perfectly sound at the fracture.
		Ultimate Deflection =1·64		

RESULTS reduced to bars 1 inch square.

	b Breaking-weight in lbs.	d Ultimate Deflection in Inches.	Product of $b \times d$ or Power of resisting Impact.
No. 10 Bar. 4 feet 6 inches between the Supports.	455	1·65	750·75

In this experiment there was increased strength, with diminished deflection, as compared with the bars previously cast from the ordinary coke.

EXPERIMENT XI,—Bar No. 11.

Cast from Eglinton, No. 4 hot-blast iron, out of the same furnace, and fused by ordinary coke. Depth of bar, 1·04 inch; width, ·941 inch;—4 feet 6 inches between the supports.

No. of Experiment.	Weight laid on in lbs.	Deflection in Inches.	Deflection-load removed.	REMARKS.
Scale.				
1	31	+		
2	87	·30		
3	143	·50		
4	199	·74		
5	255	1·00		
6	311	1·30	·12	Loss of elasticity ·02.
7	367	{ 1·62 1·64		
8	423	Broke.	··	After resisting the weight a few seconds.
		Ultimate Deflection =1·87		

RESULTS reduced to bars 1 inch square.

No. 11 Bar. — 4 feet 6 inches between the Supports.	b Breaking-weight in lbs.	d Ultimate Deflection in Inches.	Product of $b \times d$ or Power of resisting Impact.
	427	1·887	805·74

Great similarity appears to exist among all the bars cast from the ordinary coke. This was evidently a weaker iron, in its power of resistance to a dead weight, but superior in its power to resist impact, when compared with the same iron fused by the purified coke.

EXPERIMENT XII,—Bar No. 12.

Cast from Eglinton, No. 4 hot-blast iron, fused by ordinary coke. Depth of Bar, ·973 inch; width, ·944 inch;—4 feet 6 inches between the supports.

No. of Experiment.	Weight laid on in lbs.	Deflection in Inches.	Deflection-load removed.	REMARKS.
Scale.				
1	31	+		
2	87	·30		
3	143	·50		
4	199	·70		
5	255	·90		
6	311	1·17	·13	No change after weight being restored.
7	367	1·43		
8	395	1·52	·17	
9	423	Broke.	..	All sound.
		Ultimate Deflection = 1·62		

RESULTS reduced to bars 1 inch square.

No. 12 Bar. — 4 feet 6 inches between the Supports.	b Breaking-weight in lbs.	d Ultimate Deflection in Inches.	Product of $b \times d$ or Power of resisting Impact.
	441	1·69	745·29

The last three bars experimented upon were almost identical in colour and appearance; they, however, wanted the sharp granulated texture which indicated the appearance of those melted by the purified coke, and they were also defective in

the rigid character which that iron represents, when subjected to a transverse strain.

The following additional experiments have been made subsequently to those given in the body of the Paper:—

EXTRACTS from Results obtained at the Works of Messrs. JOHN GALLOWAY and SON, Engineers, Manchester, on the 27th February, 1853.

All the bars were 1 inch square, and the distance between the supports was 4 feet 6 inches.

IRON.	ORDINARY COKE.		PURIFIED COKE.	
	Breaking-weight.	Deflection.	Breaking-weight.	Deflection.
Gartsherry	514	1·44	549	1·29
Shelton	598	1·37	652	1·50
Mixture of Irons . . .	612	1·35	661	1·49
Mean . . .	575	..	621	..

Improvement 8 per cent.

EXTRACTS from Results obtained at Messrs. FOX and HENDERSON'S, London Works, near Birmingham, 17th June, 1853.

All the bars were 1 inch square, and the distance between the supports was 4 feet 6 inches.

IRON.	ORDINARY COKE.		PURIFIED COKE.	
	Breaking-weight.	Deflection.	Breaking-weight.	Deflection.
Gibbon's No. 3	448	1·06	493	1·25
	428	1·03	520	1·30
	..	..	528	1·23
Mean . .	435	..	514	..
Mixture of Iron . . .	428	1·11	468	1·22
	425	1·11	460	1·16
	400	1·24	450	1·13
Mean . .	417	..	459	..

Showing a per centage of

18 per cent. in No. 3 iron; and

10 per cent. in the mixture of iron, when fused by the purified coke.

Mr. Fairbairn said he could add little to the Paper, except by stating his conviction, that the process of purifying had a decidedly beneficial effect on the quality of the coke, and hence on the iron, whether smelted by it in the blast-furnace, or remelted in the cupola. He had found some inferior iron, when remelted with the purified coke, equal in strength to the best cold-blast mine iron. In fact the general results exceeded his expectations, and he thought it would be useful to demonstrate to the members, that it was possible to insure greater strength in ordinary cast iron, by greater care in the process of remelting and the use of purified coke. Whilst the use of hot-blast, in smelting iron, was so general, any process whereby the strength of iron could be rendered more uniform, must be valuable. He did not mean to assert, that the use of hot-blast, *per se*, was detrimental, but it permitted the abuse of working up inferior mine and of using quantities of slag, which certainly injured the quality of the iron.

Dr. Percy said this was an important question in metallurgy, and he must own he was not prepared to admit some of the results brought forward. The influence of small quantities of foreign substances might be great and prejudicial in crucible experiments, but he thought deductions from them could not be assumed to be analogous to the result of the processes on the large scale. He decidedly dissented from the correctness of the statement of the practice of working blast-furnaces; much greater chemical knowledge and practical skill were exhibited, and the iron-masters were very anxious to obtain any assistance offered them by chemists, or philosophers generally. The component parts and the ordinary effects of the extraneous substances of the materials used for making iron, were well understood by the iron-masters. They tried to get rid of the sulphur, because it imparted red-shortness, and they watched with care the appearance of the tuyères, and the colour and quality of the slag. What was called a good slag was found, on analysis, to contain precisely what had been ascertained to be the best proportions of the materials for making iron.

He could not admit the statement relative to the action of the lime upon the chloride of sodium, and would suggest more careful experiments on the subject.

He would beg it to be understood, that his remarks were not intended to depreciate the merit of the process, but as suggestions for some further investigation of so interesting a subject.

Mr. Blackwell must, as a smelter of iron, dissent from the remarks as to the carelessness, stated to be exhibited in the production of iron. In all well-regulated works the greatest attention was paid precisely to those points, upon which the Author had animadverted. The proper proportions and the due admixture of various ores were now better attended to, than at any previous period in the history of iron-making, and yet the quality of the iron produced in the olden time was vaunted as being very superior to the present product. It was only by great attention, that the iron could be prevented from being either cold-short, or red-short, and that such attention was paid, was demonstrated by the diminished consumption of limestone and of coal, per ton of iron produced. The quantity of iron, now produced in this country, was greater than ever, and there did not appear to be any chance of the demand diminishing; therefore, the discovery of any new mineral beds, such as those of Middlesborough-on-Tees and of Northamptonshire, had become of great value, and when the iron-makers of an inland district sent for their minerals, not only from the new localities he had named, but also from Lancashire, North Wales, and the Forest of Dean, it was scarcely just to brand them with want of energy, as well as want of skill. The fact was, that in the iron trade, as in every other manufacture, if a good price was paid, a good article could and would be produced, and the innovators were always too well aware of their own interests, to reject any process by which a positive improvement, or economy could be effected.

Chloride of sodium had been tried in the furnaces in South Wales, without any beneficial result; but it had the inconvenience of making the furnace scour; indeed among furnace managers of twenty years back it was not unfrequently used for that express object.

Mr. Gibbs said it was well known, that the richer and purer iron ores could not be smelted, without an admixture of weaker ores. The process of iron-making was purely chemical, and required unceasing care, not only in the preliminary mixture

and proportions of the materials, but in the mode of treatment. The kind of practical skill, required for the working of blast-furnaces, could only be attained by long practice, and appeared to consist chiefly in the careful observation of the slag and of certain indications by the tuyeres of the state of combustion of the materials. The greater the quantity produced, the greater appeared to be the difficulty of obtaining an uniformly good quality. When the supplies of iron were, to some extent, drawn from Sussex and the adjoining counties, the ore was smelted by charcoal, in furnaces producing about 5 tons per week; the quality of the metal was excellent and the price enormous; but now, when a different kind of ore was used, the smelting was performed by pit coal, and 100 tons per week was by no means an unusual quantity for a furnace, the quality had degenerated, as the selling price decreased. The iron masters could make good iron if they were adequately remunerated, but they, unfortunately, rather aimed at quantity than quality, and instead of emulating the slow process of the old charcoal furnace, wherein the chemical combination was perfect, they endeavoured by intense combustion, to induce the same effects in less time, but to the injury of the quality. They were well aware of the prejudicial effect of extraneous substances, especially of sulphur, and, he must so far disagree with the Author of the Paper, as to assert, that the iron masters did use all care and diligence in the selection and admixture of the materials, and knowing them to be a shrewd, enterprizing class, he felt convinced that if Mr. Calvert's, or any other process was proved to be of practical advantage, it would be adopted. There did appear to be every reason for believing this addition of chloride of sodium, would have the effect of depriving the coke of its sulphur, and so far, he conceived, it must prove advantageous.

Mr. Fairbairn, in answer to a question from Mr. Cottam, stated that he had tested all the various qualities of iron produced by smelting with anthracite coal, under Crane's and other processes, and did not find them so strong as the "Ponkey" iron.

He must do the iron masters the justice to say, that though, like all other manufacturers, they sought to augment the quantity of their produce, they were well aware of the advantage of a good reputation for quality, and they neglected no means of

insuring the production of good iron. The object of the Paper was to point out a cheap system of ameliorating the quality of iron, by ridding the materials of the sulphur, a substance which was admitted to be, perhaps, the most detrimental to the quality of iron; and he believed the admixture of chloride of sodium, as described in the Paper, would have the effect there stated.

Mr. W. Bird directed attention to the fact of much of the cheap iron produced in such large quantities in Scotland, from the rich black-band and other ores, by the agency of hot-blast, being sent into districts where it was worked up with charcoal iron, ostensibly for the purpose of improving it; although the Scotch pig, when imported to such distant districts, was more expensive than the indigenous iron.

Mr. C. May begged to recal the speakers from the consideration of the qualities of iron, to the real object of the Paper, which was to point out a simple and inexpensive means of getting rid of the sulphur of the coke, which was detrimental to the quality of the iron smelted by it. He admitted, that it was not easy to procure good iron, except at a very high price, and therefore if the system proposed, really had the effect of ridding the coke of the sulphur, it would be hailed as a great benefit, and would doubtless be adopted. Theoretically it did appear to be based on sound chemical principles, but he had not seen any furnaces working under the process, and therefore could not offer an opinion as to any practical disadvantages it might possess; although he did not apprehend the existence of any, that could not be overcome by the attention and known skill of the furnace managers.

Mr. Locke, M.P., V.P. said the consideration of the method of depriving the coke of its sulphur, only led to the really more important question of the means of improving the quality of the iron produced. There could not be any doubt of the fact, of the iron now made, not being of so good a quality as it used to be; whether that arose from carelessness in the manufacture, or from a desire to unduly augment the produce of the furnace, he could not offer an opinion, but he must assert the fact. The Engineers only wanted to ascertain where good iron was to be obtained, and any process tending to improve the quality, must be looked upon as a boon to the profession; whilst the Institution would always receive with pleasure the description of any such

system. Still it was necessary to examine the theory very critically, and not to receive blindly, the assertion of results stated to have been arrived it.

Sir C. Fox said he believed the bad quality did not arise so much from carelessness, or the desire to produce a large quantity of iron, as from the constant demand of the purchasers for a cheaper article.

Mr. Brunel, V.P. must protest against the promulgation of so incorrect a statement as that just made. He must assert the contrary, and he believed he should represent correctly the feelings of every Engineer of eminence in the profession, when he stated, that they used all their influence to obtain the production of a good quality of iron, at any price. They knew the importance of good quality, and the fatal effects of using materials whose quality could not be depended on. Therefore they never regarded price, when in comparison with quality; it did, however, appear, that the manufacturers of rails cared very little whether they produced a good quality, or not; it did not seem to be worth their while to try to do so.

Mr. Crace Calvert said he had entered so fully, in the Paper, into the particulars of the process, and Mr. Fairbairn had given so accurate an account of the results, as to preclude the necessity of going further into the details; he must, however, exonerate himself from the charge of misrepresenting the present state of the manufacture of iron. He had accurately described the proceedings, at some of the works he had examined, and he was ready to admit, that in others he had found a greater amount of chemical knowledge, and practical skill; but those cases were rather exceptions than instances of the general rule. No doubt when there was plenty of good iron ore in stock, there was regularity both in the selection, and in the proportions of the materials, but if the stock fell short, either from the miners not working, or from any other cause, whilst there was a considerable demand for iron, irregularities did occur. Inefficient supervision, and want of skill produced the same prejudicial effect. He did not mean to censure the iron-masters collectively, but knowing, as had been generally admitted, that there were complaints of deterioration in the quality of the iron now produced, he had desired to allude to the fact, when pointing out an easy remedy. The iron masters knew how to make

good iron, and he trusted the indication of so simple a process as that he described, would induce them to use greater efforts for attaining so desirable an end.

It was generally admitted, that the slags were sulphurous, and as large quantities were used to mix with the iron ore, there was evidently great necessity for the employment of some medium, for neutralizing their prejudicial effect. This, he contended, could be best accomplished by the use of chloride of sodium, which took up the sulphurets, and formed a new combination, leaving the metal in a purer state. The quantity of sulphur in iron rarely exceeded one per cent., therefore the quantity of chloride of sodium to be exhibited was neither expensive as a material, nor troublesome as an addition in the practical working. It was acknowledged, that in the ordinary process, whenever slag was used, it was necessary to neutralize the prejudicial effects, by augmenting the usual quantity of lime; now, he contended, this was more easily and more cheaply done by the new process.

He was aware of the chloride of sodium having been tried in the blast furnaces, at the Ebbw Vale and other works, and of its not having produced any good effects; he had anticipated such a result, because the experiment, at Ebbw Vale, had been tried, not according to the system he had prescribed, but by throwing on the dose between the charge of ore and the charge of lime; the proper chemical combination, therefore, did not take place, and the trial was a complete failure. Another experiment had been subsequently tried in the same furnace, with the proper proportions, and in the proper manner, with perfect success.

As to the removal of the sulphur from the coal, during the process of coking; the fact could not be doubted. On the Lancashire railway this had been very clearly demonstrated, not only by laboratory experiments, but by the appearance of the incandescent fuel, and by the total absence of action upon the tubes of the locomotive boilers. If coke could be so easily deprived of the most unpleasant, as well as the most noxious ingredient it contained, and which was the chief cause of its being complained of, as a general fuel, he must protest against the prejudice, which could alone militate against the adoption of so simple a remedy for a great evil.

Mr. Rendel, President, said, he could not help adding his testimony, as to the difficulty of procuring uniformly good iron; and as that material now entered so largely into almost every engineering work, it was of vital importance to encourage the trial of any system, whereby an amelioration could reasonably be anticipated. It did appear, that the quality of iron became deteriorated, nearly in proportion to the increased demand, and it was very probable, that the statement of the difficulties, frequently experienced by the iron masters, in procuring sufficient supplies of iron ore of uniform quality, gave the correct elucidation of the causes of the bad quality complained of. If, then, as there did not appear any reason for doubting, by so simple a process as the addition of a small quantity of so inexpensive a substance as chloride of sodium, any improvement in the quality of iron could be effected, and the sulphur could be so far expelled from the coke, as to render its vapours less injurious to copper, whilst it could be more generally used as fuel, the Author of the Paper had conferred a great benefit, not only on the profession, but on society at large.

March 8, 1853.

JAMES MEADOWS RENDEL, President, in the Chair.

No. 887.—"Experimental Investigation of the Principles of the Boilers of Locomotive Engines."[1]—By DANIEL KINNEAR CLARK (Edinburgh), Assoc. Inst. C.E.[2]

THE magnitude of the locomotive power employed in this country, and the costliness of the machines provided for dispensing that power, render it very desirable, that fixed and ruling principles should be established, for designing and proportioning the locomotive and adapting it to its duty. At the present day, such leading principles are eminently required, for the most diametrically opposite plans for working out the requirements of locomotion, are frequently advocated and sustained with equal confidence and apparently with equal plausibility. The existence of the locomotive properly dates from the period of the Liverpool trials, in 1829; immediately after which the general design was matured, horizontal cylinders, connected directly with the driving axles, were placed in front, the boilers were fitted with internal fireboxes and multitubular flues, and the required rate of combustion, for generating a sufficiency of steam, was enforced by the use of the blast-pipe. The advantage of a great area of heating surface was so generally understood, that the multitubular form of flue, was at once received, without hesitation, and was unanimously adopted. This, in conjunction with the internal firebox, was eminently successful, and until the present day it has maintained its position, as the most generally perfect boiler for locomotives. The position of the cylinders, horizontally, or nearly so, has also for obvious reasons remained unchanged, in general practice, and the blast-pipe, by its unrivalled efficiency, and simplicity, has been and is likely to remain the prime stimulator of combustion. Some of the most prominent points, on which railway-engine practice is at

[1] The discussion upon this subject was extended over part of four evenings, but an abstract of the whole is given consecutively.

[2] The author was elected Assoc. Inst. C. E. February 7, 1854.

variance, were brought out during the discussion of the gauge question, and much useful evidence was elicited on the performance of locomotives. There was much also that was contradictory, and the confusion that resulted from the mixed quality of the evidence and perhaps, also, from the desultory manner in which it was delivered, indicated the partial and superficial nature of many of the views entertained. Long boilers were pitted against short boilers, large fireboxes against small ones, outside cylinders against insides, low engines against high ones, and—so much importance was attached to the height of the centre of gravity and the distribution of the load,—that a species of passenger-engine was introduced, in which the driving-wheels and axle were removed to the back of the firebox, by which any size of wheel might be combined with a low centre of gravity. The feverish competition which gave birth to the very powerful and heavy engines of 25 tons and upwards, which have been and are employed indiscriminately on all kinds of traffic, was succeeded by a partial reaction in favour of very light engines of 10 tons to 14 tons, carrying their own coke and water, for the lighter traffic; and even now, many Engineers, returning from the extreme to which they had been led, by the impulse of the time, are adopting a more substantial and heavier class of tank-engines, neither so heavy as the ordinary engine and tender, nor so light as the lilliputian class, which immediately preceded them.

The locomotive is a compound machine, consisting of the boiler, the engine, and the carriage; to the first element chiefly, it is now proposed to direct attention. The distinction of the boiler and the engine should not be overlooked, as it is very possible, that a good engine and a bad boiler may be conjoined, and *vice versâ;* and the general performance may be the same in both cases, leaving a casual observer to conclude, that the machines are on the same grounds equally good, or equally bad.

The essential characteristics of a good and efficient locomotive are,—

1st. That the boiler should generate steam economically and sufficiently, for the requirements of the engine.

2nd. That the engine should employ the steam economically for propulsion.

3rd. That the whole machine, as a carriage, should run steadily and freely at all speeds.

I. The physiological conditions of excellence in the boiler, are mainly, that the fuel be effectively consumed and that the heat of combustion be completely absorbed by the water. On the question of combustion, a direct test is supplied, in the weight of water evaporated by a given weight of fuel. Carbon is the main element in both coal and coke, and a perfectly pure coke would consist entirely of carbon. It is found by general experience, and is recorded in the experiments of the Commissioners on Coals suited to the Royal Navy,[1] that the quality of coal, as a source of heat by combustion, is very much in proportion to the per-centage of carbon in its composition, and is practically unaffected by the component hydrogen; and this holds good, notwithstanding the greater heat disengaged by the combustion of hydrogen, which is usually found in excess in the coal, when the carbon is deficient. These results, apparently irreconcilable, may be explained by the fact, that in the formation of carbonic acid, the product of the perfect combustion of carbon, the volume of the new gas, is the same as that of the oxygen, with which it is formed, at the same temperature; whereas, in the formation of aqueous vapour, by the union of hydrogen and oxygen, the new gas assumes double the volume of the oxygen gas, from which it springs. While, therefore, there is no loss of heat, in the formation of carbonic acid, by enlargement of the volume of the constituent gas (oxygen), independently of temperature, there is a loss in the formation of aqueous vapour, by the heat absorbed, due to the expansion of the oxygen into twice its elementary volume, while raising the hydrogen from the solid to the gaseous state. Thus, the heat-evolving, or evaporative power of coal, is simply that of its constituent carbon; and the combustion of coke, as the best representative of carbon, and as the fuel most extensively employed in locomotives, is that which will now be submitted for examination.

By the most delicate laboratory experiments it is found, that one pound of solid carbon is capable of raising by complete

[1] Vide "Report on the Coals suited to the Steam Navy," by Sir H. De la Bêche and Dr. Lyon Playfair. London, 1848.

combustion, 14000 lbs. of water through 1 degree of temperature; or, as an equivalent, 12 lbs. of water at 60° into 120 lbs. steam; and the result is not materially different for other pressures. Now, in well-designed locomotive boilers, 1 lb. of coke evaporates 9 lbs. of water, leaving an equivalent of 3 lbs. of water unevaporated, or 25 per cent. of the whole heat unemployed, in the heat carried off by the gases in the smokebox and in other ways. The quantity of heat thus lost, may be estimated, in terms of the volumes and specific heats of the gases; 160 cubic feet of air at 60°, are chemically necessary to convert 1 lb. of pure coke into carbonic acid, to which may be added, according to the best authorities, a surplusage of 25 per cent. for leakage of air unconsumed, making a total of 200 feet of air. Assuming for the present, that the carbon is perfectly converted, absorbing the oxygen contained in 160 feet of air, there should result a mixture of carbonic acid, nitrogen, and air, escaping by the chimney. The temperature in the smokebox averages 600° when the evaporation reaches 9 lbs. of water per lb. of coke, and the heat carried off, must be such as would raise the gaseous mixture 540°, or from 60°, the ordinary temperature, up to 600°. As 160 feet of air contain 32 feet of oxygen and 128 feet of nitrogen, the component gases in the smokebox, due to the combustion of 1 lb. of coke are,

32 feet of carbonic acid (oxygen and carbon),
128 feet of nitrogen,
40 feet of air,

200 feet of gases at 60°.

The heat required to raise these gases through 540°, to the temperature in the smokebox, may be estimated, in terms of their volumes and capacities for heat, as given in the usual tables, and it is such as would raise 2316 lbs. of water through 1 degree, amounting to 16½ per cent. of the total heat of 1 lb. of coke. This leaves, out of 25 per cent., only 8½ per cent. of possible loss, by imperfect combustion, supposing the coke to be pure; and such a small per-centage is readily attributable to impurities and waste. The performance of 1 lb. of coke may then be accounted for as follows, in parts of the possible maximum performance of pure coke completely consumed:—

75	per cent. in the formation of steam,
16·5	per cent. loss by the heat of the gases escaping in the smoke-box,
8·5	per cent. drawback by ashes and waste,
100	parts.

This analysis proves that the combustion of coke, in the locomotive, is practically perfect, and that nothing can be gained by expedients designed to improve its combustion. The estimated drawback by ashes, &c., is very moderate, and certainly does not appear at all too much, considering the continual visible loss, in small particles, of even the best coke, drawn through the tubes and otherwise. An evaporation of at least 9 lbs. of water per lb. of good coke is always obtained, when the boiler is well adjusted to the rate of combustion, and increased economy of heat can be looked for, only by utilizing the heat carried off by the gases of combustion.

Taking then, as an index, the evaporating performance of coke, in suitably proportioned boilers, it is found, that efficiency of combustion in locomotives does not depend on the strength of the draught; indeed, in practice, this has nothing to do with it, for the best results have been obtained, at very various rates of combustion, from 40 lbs. up to 150 lbs. of coke per foot of grate per hour, and, of course, with very various draughts. Slow draughts and slow rates of combustion are, certainly, deemed the most favourable, both in stationary and in locomotive boilers; and reference, in support of the opinion, is made to boilers in which the rate of combustion is reduced to a minimum with economical results. But there are two ways of practising economy,—by perfect combustion and by perfect absorption of heat, and while, notwithstanding a quicker draught, the fuel may be quite as well burnt, yet more heat may be carried off into the chimney and less water be evaporated. Thus the greatest economy does not necessarily depend on reducing the rate of combustion, but on adjusting it to the absorbing power of the heating surface.

Extensive and well-arranged heating surface is the prime requisite in a good boiler, and is of equal importance with the proper generation of heat. In the earlier days of locomotives, when the heating surface was very limited, red-hot smokeboxes and chimneys were common occurrences, as the demand for steam, required a strong blast, a quick draught, and rapid com-

bustion, and while the immediate object of rapid evaporation was gained, it induced a considerable waste of heat and reduced the efficiency of the fuel.

As experience has amply proved the advantage of an abundance of heating surface, it is not necessary, at present, to adduce particular evidence in point. It will afterwards be shown how the necessary extent of heating surface is affected by circumstances. Meantime it is expedient to enquire how its efficiency is affected by its position and by its internal distribution and arrangement.

First, as to the relative importance of the heating surface of the firebox and that of the tubes. It is thought, that as the firebox is exposed to the radiant heat from the fuel, as well as the heat of the gases in contact with its surface, by which alone the tubes are heated, the former is essentially better than the latter, and that, therefore, firebox-surface should be extensively introduced. It appears to be forgotten, that what is gained in radiant heat, is lost in conducted heat, and that the total heat of combustion is the same, in whatever proportions it may be applied by radiation, and communication. It appears in some cases to have been thought, that there is a superior strength in heat by radiation, in virtue of which more rapid and more economical evaporation is obtained, than can be effected by communicated heat. Sound practice has never warranted such a conclusion: and inasmuch as, in the locomotive boiler, it is desirable rather to distribute, than to concentrate evaporation, it is preferable to moderate the evaporative function of the firebox, and to discharge the body of the heat into the tubes for absorption.

That firebox-surface should be more active than tube-surface, per unit of area, is a simple consequence of its proximity to the fire, much in the same way that the nearer tube-surface is more active than the more remote. If heat were to operate more effectively by combined radiation and contact—that is, if it were to evaporate more water, than if only communicated—there might be good reason for extending the firebox-surface to the utmost limit, in fact to have all firebox and no divided tube-surface at all. The principle, if good, leads to this conclusion, and thus would return to the primitive boiler of the Killingworth Railway—at the point from which the modern locomotive-boiler sprung into existence.

The notion of the peculiar value of firebox-surface was started by some early experiments, in which it was found, that the firebox raised three times as much steam, per foot of surface, as the tubes. Of course the more slowly the combustion proceeds, the greater is the proportion of steam raised by the firebox; and *vice versâ*, as the combustion is quickened, the greater is the proportion of steam raised by the tubes. It is plain, that the relative performance of the firebox and the tubes must be very variable, and that moreover, the value of the tube-surface diminishes, as it recedes from the firebox; and it is injudicious to seek to perpetuate any such distinctions.

Another circumstance, which gives significance to firebox-surface is, that the evaporative power of locomotives is found to vary very much with the area of that surface: and so closely does the relation subsist, that Mr. Gooch inferred, from a number of examples, that in general, the evaporative power of a boiler was expressible by two cubic feet of water per foot of firebox-surface, per hour. Now, though the ratio, thus assumed, may be considered as generally a safe one, it is clear, that as the tubes confessedly raise the greater part of all the steam generated, the firebox-surface can be accepted only as an index to the evaporative power of the boiler, and not as the leading source of the power itself. The true, natural, and fundamental measures of evaporative power, are the area of firegrate and the heating surface as a whole. With a suitable grate, and a proper distribution of the tubes, it matters nothing for economy, or for evaporative power, what area of firebox-surface is used. Nor is it difficult to explain the generally uniform relation of the firebox-surface to the evaporative power: fireboxes are similar in form, or nearly so, and consist of six sides, of which one side is occupied by the grate, and the remaining five sides constitute heating-surface. It is natural, then, that as in this way the ratio of firebox-surface to the grate area should be pretty much the same, in different boilers, the evaporative power may generally bear as constant a ratio to the firebox-surface as to the grate. The use of diaphrams, or midfeathers, however, materially alters the ratio of firebox-surface, the grate being the same. The ratio is also affected by an increase of length, or height. It is more correct, therefore, to have recourse to the area of grate as the chief datum of power. It is clear, that the grate-area is a direct measure of the combustible power, and

indirectly also of the evaporative power; "in fact," as observed by Mr. Stephenson, in 1845, "the power of the engine, supposing the power to be absorbed, may be taken to be directly as the area of the firegrate, or the quantity of fuel contained in the firebox."

The considerations which lead to the amount of firebox-surface, *per se*, being regarded with indifference, lead also to the abandonment of midfeathers, corrugated plates, and other expedients for increasing it. Midfeathers, except perhaps in very large fireboxes, are inconvenient: as if inserted transversely, though they accelerate the combustion in front, they seriously retard it behind them, by choking the draught; and, if placed longitudinally, they block up the single doorway, or require two distinct apertures, besides increasing the labour of attention to the state of the fire. It is true, that by the introduction of a midfeather, the evaporative power of boilers has, in some cases, been found to be increased, just as it would have been, by so many extra tubes; but in other cases it has not done any appreciable good: and it will generally be found, that where midfeathers have been introduced with advantage, there has been a previous deficiency, or mal-arrangement of the tube-surface.

As to the extent and arrangement of the heating-surface, generally, for the due absorption of heat and the economical generation of steam, the amount of surface depends upon the area of the grate and the required rate of evaporation. That it should increase in some ratio with the evaporation, may readily be granted; but it will not be generally admitted that area of grate has anything to do with it. Grate-surface is, however, a most important element, and is one which requires careful adaptation to the other elements, and this consideration alone would establish the propriety of referring to the grate-area, as the measure of power. The question, in short, resolves itself into the mutual adjustment of the necessary rate of evaporation, the grate-area, and the heating-surface, consistent with the economical generation of steam.

A cursory review of the known performances of locomotives, will place the subject in a better position or discussion; in Table I., pages 390-91, a selection of results are given, worked out from the recorded data, and taken from boilers of very various magnitude and proportion.

TABLE No. 1.—PERFORMANCES of LOCOMOTIVES of various Prop[ortions] Heating-surfa[ce]

Name of Engine.	Name of Railway.	Tubes. No.	Tubes. Outside Diameter.	Tubes. Length.	Tubes. Clearance.	Areas. Grate.	Areas. Firebox.	Areas. Tubes.
			In.	Ft. In.	In.	Sq. ft.	Sq. ft.	Sq. ft.
Killingworth (old)	Killingworth Railway.	1	22	5 0	. .	7·0	11·5	29·75
Ditto (improved) .	Ditto . .	43	2	4 6	. .	10·9	22·5	101·5
Sanspareil . . .	Liverpool and Manchester Railway.	1 (returned.)	24 to 15	11 0	. .	10·0	15·7	74·6
Rocket	Ditto . .	25	3	6 0	$1\frac{1}{2}$	6·0	20·0	118·0
Atlas.	Ditto . .	65	$1\frac{5}{8}$	8 0	. .	9·2	57·0	197·0
Star	Ditto . .	92	$1\frac{5}{8}$	8 0	. .	7·76	49·7	279·0
Vulcan, &c.. . .	Ditto . .	108	$1\frac{5}{8}$	7 0	. .	6·5	36·74	282·0
Hecla	Grand Junction	117	$1\frac{5}{8}$	8 $6\frac{1}{2}$	. .	8·34	45·4	373·0
Stephenson's early 6-wheels	——	124	$1\frac{5}{8}$	7 10	$\frac{3}{4}$	9·46	50·0	432·0
Bury's 4-wheels. .	London and Birmingham Railway.	97	2	8 9	$\frac{3}{4}$ to 1	9·2	51·0	410·0
Ixion.	Great Western Railway	135	2	10 3	1	13·4	97·0	602·0
Ajax class . . .	Ditto . .	178	2	10 3	. .	13·67	109·0	879·0
Pyracmon class. .	Ditto . .	219	2	10 $9\frac{1}{2}$	$\frac{7}{16}$ bare	18·44	123·0	1137·0
Great Western . .	Ditto . .	278	2	10 $10\frac{1}{2}$	. .	22·64	145·0	1455·0
Great Britain and Iron Duke .	Ditto . .	303	2	11 3	$\frac{1}{2}$	21·0	142·0	1627·0
Great Britain variety	Ditto . .	,,	,,	,,	,,	,,	,,	,,
Courier variety. .	Ditto . .	303	2	11 0	$\frac{1}{2}$	23·62	149·7	1590·0
Snake	London and South Western Railway	181	$1\frac{7}{8}$ / $1\frac{3}{4}$ at firebox.	10 $3\frac{1}{2}$	$\frac{1}{2}$ & $\frac{5}{8}$ at firebox.	12 4	75·0	823·5
A	York and North Midland Railway	140	$1\frac{3}{4}$	13 0	$\frac{1}{2}$	9·6	63·0	840·0
Hercules. . . .	Ditto . .	to	to	to	to	9·6	58·0	770·0
Nos. 54, 86 . . .	Midland Railway	150	2	13 6	$\frac{5}{8}$	9·6	63·0	840·0
Sphynx	Manchester, Sheffield, and Lincolnshire Railway.	142	$2\frac{1}{8}$	14 $3\frac{1}{4}$	$\frac{9}{16}$	10·56	86·7	865·0
Passenger Engines, No. 51, &c.	Caledonian Railway.	158	$1\frac{3}{4}$	10 2	$\frac{11}{16}$	10·5	51·0	646·2
Ditto, No. 13 . .	Ditto . .	,,	,,	,,	,,	,,	,,	,,
Ditto, No. 33 . .	Ditto . .	156	1	10 2	$\frac{5}{8}$	10·5	51·0	702 0
Goods' engines, No. 124, &c.	Ditto . .	193	$1\frac{7}{8}$	10 5	$\frac{3}{8}$	11·37	62·6	898·0
Ditto, No. 102 . .	Ditto . .	178	$1\frac{7}{8}$	10 6	$\frac{1}{2}$	11·8	58·5	818·8
Orion, and Sirius .	Edinburgh and Glasgow Railway.	125	2	10 6	1	12·23	70·75	623·7
Pallas	Ditto . .	134	2	10 6	$\frac{3}{4}$	16·04	82·14	668·7
America, and Nile	Ditto . .	110	2	11 8	1	11·10	64·3	595 0
Orion.	Glasgow and South Western Railway	88	$2\frac{1}{8}$	9 0	. .	9·24	53·8	401·7
Queen class . . .	Ditto . .	107	$2\frac{1}{8}$	10 6	$\frac{9}{16}$	10 5	64·0	570·0
Liverpool . . .	London and North Western Railway	300 {292 / 8}	$2\frac{3}{16}$ / $1\frac{3}{4}$	12 5	$\frac{7}{16}$	22·5	154·4	1950·5
McConnell's New Engine.	Ditto . .	303	$1\frac{3}{4}$	7 0	$\frac{3}{8}$	23·0	260·0	960·0
1	2	3	4	5	6	7	8	9

NOTE.—The heating surface is measured on the interior of the Firebox and Tubes.

…s. To illustrate the mutual relation of Grate-area, …porative power. 1853.

…umption of Water per Hour, steam on				Coke per Hour per foot of Grate.	Authority and Date.	Remarks.
Per Foot of			Per lb. of Coke.			
Grate.	Fire-box.	Total Surface.				
Cu. ft.	Cu. ft.	Cu. ft.	lbs.	lbs.		
2·3	1·4	·39	3·4	44	N. Wood, 1829-30.	Coal used for fuel.
4·0	2·0	·35	4·5	57	Ditto.	Ditto.
2·4	1·53	·26	2·2	69	Ditto	Fuel wasted by strength of
3·0	·91	·13	5·3	35·5	Ditto.	
5·14	·83	·186	5·37	60	Pambour, 1836 . .	Mean of 3 trips.
8·22	1·28	·193	5·52	92	Ditto	Mean of 9 trips.
9·8	1·73	·20	6·8	90	Ditto	Mean of 7 trips with 4 eng…
11·3	2·07	·225	5·63	125	Lardner & Woods, 1839.	Mean of 2 trips.
8·1	1·54	·16	7·8	65	Stephenson, 1838.	
9·24	1·67	·184	5 to 6	111	Bury, 1839.	
15·0	2·07	·29	7·0	138	D. Gooch, 1845 . .	Mean of 6 trips made f… Gauge Commissioners; …ance of tubes estimated.
11·2	1·4	·15	8·28	84	Ditto, 1848 . .	Mean of 42 trips with 3 en…
8·4	1·3	·12	7·6	69	Ditto	Mean of 48 trips with 3 en…
9·3	1·46	·13	7·4	79	Ditto, 1847 . .	Mean of 12 trips.
11·0	1·62	·13	8·32	82	Ditto . . .	Mean of 24 trips.
11·0	1·63	·13	7·67	90	Ditto, 1849 . .	Mean of 14 trips with 6 en…
8·6	1·36	·12	7·19	75	Ditto	Mean of 22 trips with 7 en…
12·26	2·63	·17	8·9	87	J. V. Gooch, 1848 .	Mean of 2 trips; tubes 1… diameter at firebox for … of length.
17·0	2·57	·18	8·8	132	D. Gooch, 1845. .	Mean of 3 trips made f… Gauge Commissioners.
14·2	2·34	·16	8·96	99	Ditto	One trip.
15·6	2·38	·16	10·0	98	Bidder	Mean of 8 trips.
22·1	2·7	·24	9·0	157	Peacock, 1850 . .	One trip
8·0	1·65	·12	9·1	55	D. K. Clark, 1850 .	Mean of 17 trips with 4 en…
11·6	2·4	·17	6·8	108	Ditto	One trip, Express.
7·0	1·43	·10	10·47	42	Ditto	Mean of 8 trips.
8·66	1·57	·10	8·17	66	Ditto	Mean of 10 trips with 3 en…
10·3	2·05	·14	6·8	93	Ditto	Mean of 3 trips.
6·29	1·09	·11	9·0	44	Ditto, 1850-51 .	Mean of 10 trips.
6·0	1·18	·13	8·8	38	Ditto, 1850 . .	Mean of 3 trips.
8·8	1·52	·15	7·88	70	Ditto	Mean of 4 trips.
9·4	1·62	·19	6·96	84	Ditto. . . .	Mean of 2 trips.
10·0	1·65	·17	7·2	87	Ditto	Mean of 8 trips.
..	..	..	..	..	. . .	No performance recorded.
..	..	..	..	..	. . .	Ditto; clearance estimated
14	15	16	17	18	19	20

Looking to the results from the early engines, made previous to 1840, the advantage of the extension of heating-surface, irrespective of local distinctions, is obvious. An extension from 41 feet, in the old Killingworth engine, to 480 feet in Stephenson's six-wheeled engine, raised not only the evaporative power from 16 feet to 77 feet of water per hour, but also the evaporative economy, in the ratio of 3¼ lbs. to nearly 8 lbs. of water per lb. of fuel: such that, while the power was increased five times, the consumption of fuel was only little more than doubled. Even 100 feet of water per hour, was evaporable with little more than 400 feet of surface, not so economically, of course, as at lower rates, but still, as with the 'Hecla' in the hands of Lardner and Woods, at a rate of 5⅓ lbs. per lb. of coke. That the economy, here referred to, is practically independent of firebox-surface, is also readily proved. Comparing the three results by Pambour from the 'Atlas,' the 'Star,' and the 'Vulcan,' it is found, that while the firebox-surface falls from 57 feet to 37 feet successively, and the evaporation per foot per hour, rises from less than 1 foot, to 1¾ foot of water, the evaporation per lb. of coke, also rises from 5⅝ lbs. to 6¾ lbs. of water:—that is, the evaporative power and the economy rise jointly, while the firebox-surface incidentally falls, showing that the latter had no part in augmenting the evaporative efficiency, and that the increase of evaporative efficiency was due, solely, to the increase of tube-surface. In fact, the tube-surface was increased from about 200 feet to 280 feet, and the whole heating-surface from about 250 feet to 320 feet, or in the ratio of about 3 to 4. Now the total evaporation was increased in the same, or a rather greater ratio, from 47 feet to 64 feet per hour, while the evaporative economy was not only undiminished, but was positively increased, in the ratio of 5⅝ lbs. to 6¾ lbs. of water per lb. of coke. Nor was the heating-surface, in the latter case, of less value per foot, for the evaporation, per foot of the whole surface, rose slightly from about ⅙th to ⅕th of a foot of water per hour. Here, then, is a very strong case: it is shown, not merely that the particular quantity of firebox-surface is a matter of indifference, but apparently, also, that firebox-surface may with advantage be replaced by tube-surface, and a superior result may be produced:—superior both in power and in economy, because the

evaporative power is not only greater as a whole, but is greater, also, per unit of the entire surface; and not only greater per unit of surface, but also more economically so. Extending the comparison to the 'Rocket,' the first tube-boiler locomotive, and to the 'Hecla,' and Stephenson's six-wheel engine, of later construction, embracing six distinct results, the same superior efficiency of extended surface of firebox, or tube, indifferently, is demonstrable. An increase of surface, from about 140 feet in the 'Rocket,' to 420 feet in the 'Hecla,' in the ratio of 1 to 3, raises the evaporation from 18 feet to 94 feet per hour, in the greater ratio of 1 to 5, and that with more economy, in the ratio of 5·3 to 5·63 lbs. of water per lb. of coke. Comparing the 'Rocket' with Stephenson's six-wheel engine, in which the evaporation is less pushed, than in the 'Hecla,' the peculiar virtue of extended surface is still more apparent: for, with surfaces in the ratio of 1 to less than 4, and evaporations per hour of 1 to 4½, in a ratio sensibly greater than the surfaces, the poundage of water, or economy of evaporation, rose from 5·3 lbs. to 7·8 lbs. per lb. of coke, in the ratio of 2 to 3; showing, as before, that an extension of heating-surface does not only extend equally the evaporative power, but it does so, with very much greater economy, making each foot of heating-surface more efficient than before; in other words, a double gain in evaporative power and evaporative economy is acquired: or, if economy of evaporation be sacrificed, evaporative power may be still further greatly increased.

The question remains, to what is this increased virtue per foot of heating-surface, by simple extension, to be attributed? or, why does an addition of surface add, not merely by as much, to the whole evaporative power, but add, also, to the general efficiency per foot of surface? This question will be considered later.

Passing on to the engines of the Great Western Railway; their generally inferior economy of evaporation is, perhaps, the most remarkable feature of the experiments. With unrivalled quantities of heating-surface, their latest boilers do not raise above 7 lbs. to 8 lbs. of water per lb. of coke, even at very moderate rates of evaporation. The 'Ixion' and the 'Courier' evaporate the same quantity of water,—200 feet per hour,—with sensibly equal economy, expressed by 7 lbs. and 7·19 lbs. of

water per lb. of coke; whereas their heating-surfaces are respectively about 700 feet and 1740 feet, in the ratio of 1 to 2½, and are 52 times and 73 times the grate-area. Whether, therefore, the absolute amount of heating-surface, or its ratio to the grate, be contemplated, the 'Courier' has very much the advantage, and ought to have indicated a greatly superior evaporative economy. The 'Ixion,' in short, evaporates 2½ times the water per foot of total surface, raised by the 'Courier,' with sensibly equal economy; and it does so with a relatively larger grate, which, in itself, proved to be a disadvantage. Moreover, while the 'Ixion' raised 2 feet of water per foot of firebox per hour, the 'Courier' could raise only 1⅜ foot, with equal economy; proving how small is the influence of mere firebox-surface, in promoting economy of evaporation; and the necessity of its being properly seconded by the tubes. Comparing, again, Stephenson's early six-wheel engine with the 'Courier,' in evaporating nearly equal quantities of water, per foot of grate, the former, with a heating-surface only 50 times that of the grate, evaporates nearly the same quantity of water per foot of grate, as the latter, and about one-third more per foot of total surface, with greater economy, in the ratio of 7·8 lbs. to 7·2 lbs. of water.

Reverting to the comparison of the Great Western engines amongst themselves, it is clear, that the increase of tube-surface, beyond a certain limit, has not added to the economy, and the advantage appears to terminate with the 'Ajax' class, in which 880 feet of surface is obtained with 178 tubes. The barrels are sensibly of the same length, 10 feet to 11 feet, and the tube-surface is increased, consistently with Mr. Gooch's principle of short boilers, by increasing the number of the tubes. It must be then concluded, not that tube-surface must cease to be useful, beyond a certain limit, where heat remains for absorption, for that would imply, that the absorbing function ceased, at temperatures considerably above that of the steam; but that, in the particular cases, the tube-surface is imperfectly arranged,—that there is, in fine, a deficiency of clearance, between the tubes, for the circulation of water and steam. From the 'Rocket,' with 1½ inch of clearance, down to the 'Hecla,' the 'Ixion,' and other engines with ¾ inch to 1 inch of clearance, increase of tube-surface was regularly accompanied

by increase of economy. This proved, that the circulation was practically unimpaired; but when, as in the later Great Western engines, the tubes were increased in number, from 200 to 300, and when, in consequence, the clearance was simultaneously reduced to ½ inch or ⅜ inch, from the necessity of limiting the diameter of the barrel of the boiler, it is clear, that the facility for circulation was reduced, just when it ought to have been increased; and there is no doubt, that a deficiency of clearance is the only tangible reason for the impaired economical performance of the 'Courier' and other boilers.

The succeeding performances of the 'Snake' and the long boilers which follow it, recorded in the table, corroborate the foregoing remarks on the clearance between the tubes. With the moderate number of 140 to 180 tubes, ½ inch to ⅝-inch clear, and surfaces 72 times to 94 times the grate, and with very high rates of evaporation, from 12 feet to 22 feet of water per foot of grate, these boilers economically evaporate, an average of 9 lbs. of water per lb. of coke. They also prove the inutility of trusting to mere firebox-surface, as with very little greater proportion of total surface to the grate, than is to be found in the later Great Western engines, they evaporate equal quantities of water, more economically, with less than half the grate-area and firebox-surface.

The Author's own experiments, the results of which are placed in the last part of the table, confirm most of the conclusions already drawn from a consideration of previous experiments. With a heating-surface 66½ times the grate, No. 51, Caledonian Railway, passenger-engine, evaporates 8 feet of water per foot of grate per hour, at a rate of 9 lbs. of water per lb. of coke; and No. 33, with an extra surface 71 times the grate, evaporates nearly the same quantity, at the rate of 10½ lbs. per lb. of coke; showing that even with moderate evaporation, an increase of surface from 66½ times to 71 times the grate, very sensibly increases the economy, when there is ample clearance between the tubes. No. 13 shows the effect of urging the evaporation to 11½ feet of water per foot of grate per hour, in the reduced economy represented by 6¾ lbs. of water per lb. of coke. The space of ⅝ inch clearance of the tubes is certainly sufficient for their number, according to previous experience; and it would seem, that for these boilers, with sur-

faces 66 times the grate, 8 feet of water per foot of grate per hour, is the measure of their economical evaporation, at the assumed standard of 9 lbs. per lb. of coke. Going on to the Caledonian Railway goods'-engines, where the clearance is only ½ inch and ⅜ inch, with nearly 200 tubes, and a surface 75 times to 85 times the grate, the tube-surface is extended, no doubt, beyond the useful limits, as, with only 8½ feet of water evaporated per foot of grate per hour, little more than in No. 51, and with a large excess of heating-surface, No. 125 raises only 8 lbs. of water per lb. of coke. And, comparing No. 13 and No. 102, with surfaces 66 times and 74 times the grate respectively, the former, with the fewer tubes and the greater clearance, evaporates more water per foot of grate per hour, than the latter, and with the same economy—6·8 lbs. of water per lb. of coke. These comparisons show, not only, that an extension of tube-surface, beyond the limits necessary for free circulation, is not merely less useful relatively, but is absolutely useless, and unquestionably injurious to the functional action of the boiler.

Of the Edinburgh and Glasgow engines, all of which have abundance of tube-clearance, the 'Orion' and 'Sirius,' having a heating-surface of only 57 times the grate, raise only 6¼ feet of water per foot of grate per hour, at the economical standard of 9 lbs. of water per lb. of coke. By pushing the rate to 8¾ feet per foot of grate, in the 'America,' of the same proportions, the economy falls to 7⅞ lbs. of water. The 'Pallas,' with the smallest relative surface, 47 times the grate, raises but 6 feet of water per foot per hour, with an economy of 8⅘ lbs. per lb. of coke.

Lastly, on the Glasgow and South Western Railway, the 'Orion' and the 'Queen,' with surface-ratios of 49 and 60, and evaporations of 9½ feet and 10 feet of water per foot of grate per hour, raise only 7 lbs. to 7¼ lbs. of water per lb. of coke. It is clear, that they are both deficient in heating-surface, for economical evaporation; and the 'Orion' is precisely of the stamp of the earliest engines operated on by Pambour in 1836; as, in both cases, with the same surface-ratio and evaporation, per foot of grate, the same poundage of water was evaporated.

Returning to the question of the influence of extension upon the value of heating-surface, by which the general efficiency per foot of surface, is increased; it will be found to depend, essen-

tially, upon the ratio of the heating-surface to the grate-area, so that the same increase of efficiency per foot may be effected, either by increasing the surface and leaving the grate constant, or by reducing the grate and leaving the surface constant. In the three results by Pambour this dependence is very clearly exhibited; in the 'Star' and the 'Vulcan,' with nearly equal surfaces and equal evaporations, and with grates of 7¾ feet and 6½ feet, the smaller grate evaporates the most water per lb. of coke, in the ratio of 5½ lbs. to 6¾ lbs. In the Great Western stock, the contrasts are quite as striking: thus the 'Pyracmon,' with a grate one-third larger than the 'Ajax,' evaporates the same quantity of water, with less economy, in the ratio of 8½ lbs. to 7½ lbs. per lb. of coke, even with the advantage of nearly one-third more surface. Comparing again the 'Great Britain' and the 'Courier' varieties, with grates of 21 feet and 23^{5} feet, and nearly the same surfaces, the latter evaporates less water, per foot of grate, of firebox, or of total surface, and with less economy, in the ratio of 7⅝ lbs. to 7⅕ lbs. of water per lb. of coke. The principle, here illustrated, is altogether peculiar, for it implies, that the economical evaporative power of a boiler may be increased, by leaving the heating-surface unaltered, and simply by reducing the grate: not that the quicker draught which may be necessary through a smaller grate, necessarily improves the combustion, for the quality of combustion within the ordinary limits of practice, is not affected by the draught; the question is not one of combustion, but of absorbing power, and the heat discharged from the smaller grate, more intense because generated within narrower limits, certainly operates more favourably for evaporation. This is most probably owing to the greater excess of temperature, above that of the water in the boiler, due to a more concentrated combustion, and to the speedier transmission and absorption of heat, which must take place at higher temperatures. It clearly shows the value of time for absorption, and affords an additional proof, that this element very sensibly affects the economy of evaporation.

The special advocates of firebox-surface may adduce the superiority of intense combustion, thus illustrated, in support of their opinion, in so far as it is attributable to the superior power of the radiant heat from the grate. This superiority in the smaller firebox is admitted; but it is due simply to the law,

according to which, the intensity of radiant heat varies inversely as the square of the distance from the focus of radiation. Now, comparing similar fireboxes, the surface varies as the square of the lineal dimensions directly, while the intensity of the radiant heat varies as the square of the lineal dimensions inversely; it would follow from these ratios, that what is gained in surface is just balanced by the loss of intensity of heat, and that, consequently, it is a matter of indifference to what dimensions a firebox may be enlarged. But, the argument is still less than neutral, with respect to the enlargement of the firebox; because the whole power by radiation, with the same intensity of combustion, is just constant; whereas for the production of a given quantity of steam, by the combustion of a given quantity of fuel, the intensity is reduced, as the grate is enlarged, and thus the total efficiency of the firebox-surface, and much more the efficiency per square foot, is not only not constant, but is positively reduced by general enlargement of dimensions. Indeed, a firebox may be supposed so large, as to reduce the temperature of combustion to that of the water in the boiler, if coke could burn at so low a temperature, and then evaporation would altogether cease.

It appears then to follow, that concentrated, rapid combustion is alike the true practice for the largest and the smallest boilers; and where a more moderate rate of combustion has been found more economical in locomotive boilers, it has been the result, not of a more thorough combustion, but of an original deficiency in arrangement, or extent of absorbing surface.

It appears also, that to make the most advantageous use of firebox-surface, the enlargement of fireboxes should chiefly take place longitudinally, or laterally, and not in both directions, nor vertically: so as to reduce to as little as possible the mean distance of the surface from the grate, and proportionally to increase its efficiency. Thus it is that long and narrow fire-grates are preferable to square grates.

Hence it follows, that few and long tubes, sufficiently numerous, of course, for the requirements of practice, are preferable to many and short tubes; and that the capacity of the firebox, without reference to area of grate, should be reduced *to a minimum*; for restricted capacities and flue-areas are

favourable to the concentration and forcible development of the heat, and to its absorption by the surface.

These conclusions are fortunately the most convenient for practice, as they lead directly to the adoption of small fireboxes, and moderate transverse dimensions generally; and they show, that the method of extending heating-surface by increase of length, whether in the firebox, or in the tubes, but especially in the latter, is consistent with the soundest practice, and that Stephenson's long boiler was, in all respects, a decided advance upon previously existing examples. The grate-area, which in the opinion of most locomotive engineers, can never be made too large, seriously involves the economy of evaporation, and demands, jointly with the heating-surface, to be adjusted to the requirements of the engine.

It remains now to consider what practical rules are deducible from this discussion. Assuming, as the practical standard of economical evaporation, the raising of 9 lbs. of water into steam, per pound of coke, it is desirable to construct a formula which shall embrace the three elements, grate-area, heating-surface, and economical evaporative power; and which shall mutually adjust their proportions: such that, when any two of the elements are given, the third may be found from them.

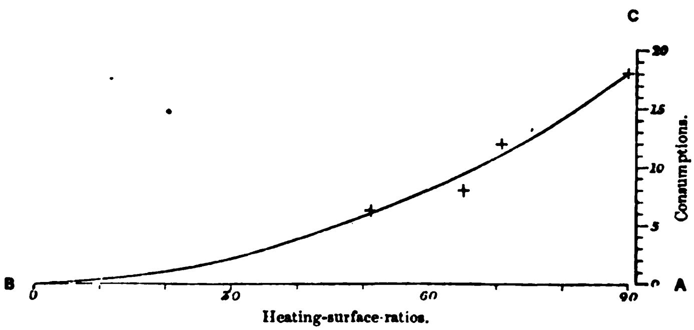
The contents of Table No. 1, page 390, afford the means of doing so. Selecting the cases of economical evaporation, the long boilers, in the first place, give a mean evaporation for the first, second, and fourth cases, of 18 feet of water per foot of grate per hour, at 8·92 lbs. of water per lb. of coke, with a mean surface-ratio of 90. Secondly, the 'Snake' evaporates 12½ feet of water per foot of grate per hour, at 8·9 lbs. of water per lb. of fuel with a surface-ratio of 72; thirdly, the Caledonian passenger-engines evaporate 8 feet of water per foot per hour at 9·1 lbs. of water per lb. of coke, with a surface-ratio of 66½; fourthly, the Edinburgh and Glasgow engines, 'Orion' and 'Pallas,' evaporate 6·15 feet of water per foot per hour, at 8·9 lbs. of water per lb. of coke, with a surface-ratio of 52. Tabulating these results, they are as follow:—

—	Surface Ratio.	Evaporation.	
		Per Foot per Hour.	Per lb. of Coke.
		Feet	lbs.
Long boilers - - - -	90	18	8·92
L. & S. W. R. engine - -	72	12·25	8·9
C. R. engines - - -	66½	8	9·1
E. & G. R. engines - -	52	6·15	8·9
1	2	3	4

The poundages of water in the fourth column are nearly identical, and may be taken at 9 lbs.; the rates of evaporation, in the third column, may therefore be adopted as the maximum economical rates, due to the surface-ratios, in the second column. The remarkable variation of economical evaporative power, shown in the third column, is clearly due to the variation of surface-ratios in the second column, and these results are sufficiently numerous and distinct to justify the construction of a formula which shall embrace them. Let the base line, A B, Fig. 1, be adopted to measure the ratios of heating surface, in

Fig. 1.

DIAGRAM to show the RATE of ECONOMICAL CONSUMPTION of WATER, per hour, per foot of Grate, for given surface-ratios.



the second column, set off at points which are 52, 66,' 72, and 90, graduations from A; and draw verticals from these points equal, by the vertical scale, C, to the respective contents of the third column, and terminated by stars. The mean curve traced through these stars, terminating at A, expresses the general law according to which the rate of economical evaporation rises with the surface-ratio. This curve comprises the individual

results very closely, and is designedly made of a parabolic form. It implies that the economical evaporative power, per foot of grate, varies with the square of the surface-ratio; and it readily yields the following formulæ:—

$$c' = \cdot 00222 \left(\frac{h}{g}\right)^2 \quad - \; - \; - \quad (1)$$

$$c = \cdot 00222 \, \frac{h^2}{g} \quad - \; - \; - \; - \quad (2)$$

in which c' is the economical evaporative power in cubic feet of water per foot of grate per hour, c is the total economical evaporative power in cubic feet of water per hour, h is the total inside heating surface in square feet, and g is the grate-area in square feet. From these formulæ the following rules for practice are derived:—

Rules I., II., III.—To find the greatest rate of consumption of water, consistent with its economical evaporation, for a given heating-surface and grate-area:—

1st. The rate of consumption per square foot of grate-area. Divide the heating-surface by the grate-area, both in supercial feet; square the quotient, and multiply by ·00222. The product is the consumption in cubic feet per hour per square foot of grate.

2nd. The rate of consumption per square foot of heating-surface. Divide the heating-surface by the grate-area, both in square feet, and multiply by ·00222. The product is the consumption in cubic feet per hour per square foot of heating-surface.

3rd. The rate of total consumption. Divide the square of the heating-surface by the grate-area, both in feet, and multiply by ·00222. The product is the total consumption in cubic feet per hour.

Rule IV.—To find the heating-surface necessary to maintain a given hourly consumption of water economically, with a given area of grate. Multiply the grate-area in square feet, by the consumption of water in cubic feet per hour, find the square root of the product, and multiply the root so found by 21·2. The final product is the area of heating-surface in square feet.

Rule V.—To find the grate-area suitable for maintaining a given hourly consumption of water, economically, with a given

heating-surface. Divide the square of the heating-surface in feet by the consumption of water in cubic feet per hour, and multiply by ·00222. The product is the area of grate in square feet.[1]

The relations, just announced, between heating-surface, grate-area, and economical evaporative power, lead to the following important conclusions:—

1st. That the economical evaporative power decreases directly as the area of grate is increased, even while the heating-surface remains the same; showing that the economic value of a given heating-surface is diminished by enlarging the grate; and inversely, that a reduction of the grate raises the value of the heating-surface.

2nd. That the economic evaporative power increases directly as the square of the heating-surface, when the grate remains the same; showing that every part of the heating-surface increases in economic value, in a compound ratio, by adding to its amount: such that, for example, doubling the heating-surface would not only double, but quadruple the evaporative power, and would double the efficiency per square foot.

3rd. That the necessary heating-surface increases, only as the square root of the required economical evaporative power, when the grate remains constant; that is, for example, four times the evaporative power would require only twice the heating-surface.

4th. That the heating-surface, to supply the same evaporative power, must be increased as the square root of the grate-area; that is, an increase of grate reduces the efficiency of the surface, such that, for example, for four times the grate, twice the surface is necessary to evaporate the same quantity of water.

It is plain, then, that the heating-surface is economically weakened, by an extension of grate, and is strengthened by its reduction: that, in short, the value of heating-surface increases rapidly with the ratio it bears to the grate, much more rapidly than the ratio itself. It follows that locomotive boilers, should be designed for the highest average rates of evaporation,

---

[1] The formulæ are regularly worked out, according to these Rules, in the "Treatise on Railway Machinery," by D. K. Clark, and the Rules are quoted from that work.

per foot of grate, that may in good practice be adopted, consistently with the highest average rates of combustion at which coke can be properly burned; as, in this way, the smallest grate and the smallest amount of heating-surface will be arrived at, and consequently the smallest and lightest boiler, consistent with the required economical evaporative power. The grate cannot be too small, nor the surface too extensive, as respects economical evaporation; and the chief limit to the smallness of grate is that imposed by the physical qualifications of coke, as fuel, to resist the violence of strong draughts, at high rates of combustion, either in lifting it bodily off the grate, or in breaking it up into fragments.

The practice of the earlier tube-boiler locomotive supplies some data on the point, as, with their imperfect proportions of boiler and engine, they were necessarily worked up to the highest rates of combustion. In these engines, 100 lbs. to 160 lbs. of coke per foot of grate per hour were consumed. Towards the latter limit, the coke, if of light and loose quality, was much shaken up and blown through the tubes. When it is sound, hard, and cohesive, coke will generally burn well at 150 lbs. to 160 lbs. per foot per hour, as is exemplified in the observations with the 'Sphynx,' class of engines, which are stated, by Mr. Peacock, to work satisfactorily even at such a high rate of combustion, and are not found materially to require more cleaning of tubes, or clearing of smokebox than is usual with other boilers. To cover all the necessities of practice, 150 lbs. of good sound coke may be fixed, as the ultimate maximum quantity which may be properly consumed, per foot of grate per hour; and to make allowance for inferior qualities, 112 lbs. or 1 cwt. of coke will be adopted for the average maximum consumption per foot of grate per hour; this determines the average maximum of economical evaporation to be 16 cubic feet of water per hour, allowing 9 lbs. of water per pound of coke. By the Rules, this rate of evaporation requires 85 feet of heating-surface per foot of grate; and therefore, in locomotive boilers, a total heating-surface equal to 85 times the grate-area is the smallest that should be adopted in practice.

Table No. 2 contains a number of examples of the economical evaporative power of locomotive boilers, for given ratios of heating-surface.

TABLE NO. 2.—ECONOMICAL EVAPORATIVE POWER of LOCOMOTIVE BOILERS, for giving ratios of Heating-Surfaces.

Rate of Heating Surface to Area of Grate. *Grate* = 1.	Economical Evaporative Power. Per Foot of Grate per Hour.	Economical Evaporative Power. Per Foot of Heating Surface per Hour.	Consumption of Coke per Foot of Grate per Hour.
	Cubic Feet.	Cubic Feet.	lbs.
30	2	·07	14
40	3·55	·09	24½
50	5·5	·11	38¼
60	8	·13	55½
70	10·9	·155	75¾
80	14·1	·18	98
85	15·9	·19	110½
90	18	·20	125
95	20	·21	139
100	22	·21	153

Table No. 3 contains the whole economical evaporative power of boilers, with various amounts of grate-area and heating-surface.

TABLE NO. 3.—OF RELATIVE GRATE-AREAS, HEATING-SURFACES, and ECONOMICAL EVAPORATIVE POWERS of LOCOMOTIVE BOILERS; deduced from practice.

Total Economical Evaporative Power, in Cubic Feet of Water per Hour.	Area of Grate, in Square Feet.													
	5	6	7	8	9	10	11	12	14	16	18	20	22	24
	Total Heating-Surfaces, in Square Feet, due to the above Grate-Areas, and the annexed Evaporative Powers.													
Cub. Ft.														
40	300	328	355	379	402	424	444	464	501	536	569	600		
50	335	367	396	424	450	474	497	519	561	599	636	670	703	734
60	367	402	435	464	493	519	545	569	614	657	697	734	770	805
70	396	435	469	502	530	562	590	614	663	709	752	793	831	896
80	424	464	501	536	569	600	629	657	709	758	805	848	889	927
100	474	519	561	599	636	670	703	734	793	848	900	948	995	1039
120	-	569	614	657	697	734	770	805	869	927	985	1039	1109	1138
140	-	-	663	709	752	793	831	869	938	1003	1064	1122	1177	1229
160	-	-	-	758	805	848	889	927	1004	1073	1138	1199	1258	1314
180	-	-	-	805	853	900	943	985	1064	1138	1207	1272	1344	1393
200	-	-	-	-	900	948	995	1039	1122	1199	1272	1341	1406	1468
220	-	-	-	-	-	1000	1042	1089	1176	1258	1324	1406	1475	1541
240	-	-	-	-	-	-	1091	1138	1229	1314	1393	1468	1541	1609
260	-	-	-	-	-	-	-	1184	1278	1367	1450	1529	1603	1675
280	-	-	-	-	-	-	-	-	1327	1435	1505	1586	1664	1738
300	-	-	-	-	-	-	-	-	1374	1469	1558	1642	1722	1799
320	-	-	-	-	-	-	-	-	-	1516	1610	1696	1778	1859
360	-	-	-	-	-	-	-		-	-	1706	1800	1886	1791
400	-	-	-	-	-	-	-	-	-	-	1800	1900	1990	2077

NOTE I.—Lower maximum rates of evaporation should be adopted for grates less than 8 feet, to meet the practical difficulties of working with very small grates, and are suggested as follows:—

Areas of grate - - - - - - - 4, 5, 6, 7, 8 sq. ft.

Suitable maximum rates of evaporation 11, 12, 13, 14, 16 cubic feet water per hour per foot of grate.

Relative consumptions of coke - - 76, 83, 90, 97, 112 lbs. per hour per foot of grate.

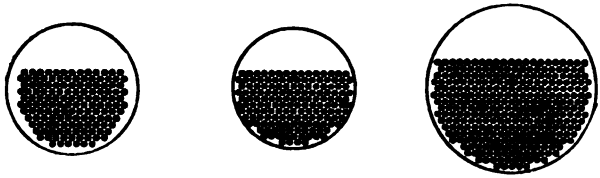
The surfaces printed in pointed type are due to evaporations of from 2 feet as a minimum to 16 feet of water per foot of grate per hour, as the average maximum of evaporation.

The heating surfaces are measured from the interior.

It has been seen, that the efficiency of tube-surface may be neutralized by a deficiency of clearance between the tubes. The long boilers, such as, for example, the 'Sphynx,' with 142 tubes, work satisfactorily with $\frac{9}{16}$ inch of clearance; and also the Caledonian engines, with 158 tubes and $\frac{11}{16}$ inch of clearance.

Fig. 2.

SECTIONS OF BOILERS, TO ILLUSTRATE FREEDOM FOR CIRCULATION.



'Sphynx,' 142 tubes. — 'Caledonian Railway,' Passenger Engine, 158 tubes. — 'Great Britain,' 303 tubes.

These are well established data, and a mean of these gives, for 150 tubes, $\frac{5}{8}$ inch of clearance, or $\frac{1}{8}$ inch for every 30 tubes. As the necessity for clearance should vary in the ratio of the whole number of tubes, the following rule will yield satisfactory results for practice:—

RULE VI.—To find the clearance between the tubes, suitable for economical evaporation, for a given number of tubes. Divide the number of tubes by 30. The quotient is the required clearance in eighths of an inch.

Table No. 4 is drawn up by the Rule, showing the necessary clearance, in good practice, for given numbers of tubes.

TABLE No. 4.—Of the CLEARANCE between the TUBES suitable for ECONOMICAL EVAPORATION, at the rate of 9 lbs. Water per lb. of Coke.

Number of Tubes.	Clearance between Tubes.	Number of Tubes.	Clearance between Tubes.
	Inch.		Inch.
Below 90	$\frac{3}{8}$	195 to 210	$\frac{7}{8}$
90 to 105	$\frac{7}{16}$	210 to 225	$\frac{15}{16}$
105 to 120	$\frac{1}{2}$	225 to 240	1
120 to 135	$\frac{9}{16}$	240 to 255	$1\frac{1}{16}$
135 to 150	$\frac{5}{8}$	255 to 270	$1\frac{1}{8}$
150 to 165	$\frac{11}{16}$	270 to 285	$1\frac{3}{16}$
165 to 180	$\frac{3}{4}$	285 to 300	$1\frac{1}{4}$
180 to 195	$\frac{13}{16}$		

The lateral clearance between the upper rows of tubes and the barrel should be at least $\frac{1}{16}$th of the diameter of barrel at each side. The diameter of the tubes is supposed to be about 2 inches.

To find the relation of the diameter of a boiler-barrel and the number of tubes which can be received by it; let it be assumed as a practical standard, that the arrangement of tubes in the boiler is to be the same as in the 'Sphynx,' by Messrs. Sharp Brothers, and Co. In this boiler the tubes are suitably apart according to the Rule, and a free water-space is allowed between the tubes and the sides, and the bottom of the barrel. In cross section, they occupy a segment of the barrel, of which the versed sine is equal to about two-thirds of the diameter; they are ranged in horizontal rows, in each of which the tubes alternate with those immediately above and below, so that the lines joining the centres of contiguous tubes form equilateral triangles, of which there are two to each tube. In spacing out the tubes, therefore, supposing the whole area of the lower segment of the barrel to be fully occupied by them, their number is expressible by the number of times that the lower segment contains the quadrangular space set off for each tube.

Let d = the diameter of the barrel,
d' = the outside diameter of tubes,
c = the clearance of the tubes,
p = the pitch of the tubes, equal to $d'+c$,
n = the number of tubes.

Then the area of the tube-segment of the barrel, of which the depth is two-thirds of the diameter, is $\cdot 55d^2$; and the area of the four-sided space for each tube is the product of the pitch, by the vertical distance apart of two neighbouring rows of tubes, or $\cdot 86\, p^2$. Then, $n = \frac{\cdot 55d^2}{\cdot 86p^2} = \cdot 62\left(\frac{d}{p}\right)^2$. But, of the total area of the tube-space, Sharp Brothers reserve one-sixth for clearance around the faggot of tubes; five-sixths of the above value of n, will therefore express the number of tubes available in good practice. Hence, finally—

$$n = \cdot 62\left(\frac{d}{p}\right)^2 \times \frac{5}{6} \text{ in practice, or}$$

$$n = \cdot 52\left(\frac{d}{p}\right)^2.$$

By this equation, may be found the diameter of barrel practically suited to contain a given number of tubes at a given pitch; or the number due to a given diameter of barrel.

RULE VII.—To find the diameter of barrel suited to accommodate a given number of tubes at a given pitch. Multiply the square root of the number of tubes by the pitch in inches, and by 1·37. The product is the diameter of the barrel in inches.

RULE VIII.—To find the greatest number of tubes which should be placed in a barrel of given diameter, and at a given pitch: divide the diameter by the pitch, both in inches, and square the quotient, and multiply by ·52. The product is the number of tubes.

As clearance is chiefly required about the centre and the upper part of the mass of tubes, to give access for the water and egress for the steam, the lower tubes may, with advantage, be placed more closely, and the upper tubes more widely than is dictated by the rule for clearance, their total number being the same; and even, where desirable, the pitch may be retained in the upper rows at the regular amount, and be gradually reduced in the lower rows, so as to increase the available number of tubes, without injuring the circulation.

The following Table is composed for two-inch tubes, and exhibits the relative diameters of barrel for given numbers of tubes, determined by Rule VII.

TABLE No. 5.

Of the DIAMETER of BARREL practically suitable for given numbers of 2-inch Tubes.

Number of 2-inch Tubes.	Pitch of Tubes, estimated from the Clearance found by Rule VI.	Diameter of Barrel.	
No.	Inches.	Ft.	In.
80	$2\frac{3}{8}$	2	5
90	$2\frac{3}{8}$	2	7
100	$2\frac{7}{16}$	2	$9\frac{1}{2}$
120	$2\frac{1}{2}$	3	$1\frac{1}{2}$
140	$2\frac{5}{8}$	3	$6\frac{1}{2}$
160	$2\frac{11}{16}$	3	11
180	$2\frac{3}{4}$	4	$2\frac{1}{2}$
200	$2\frac{7}{8}$	4	8
220	$2\frac{15}{16}$	5	0
250	$3\frac{1}{16}$	5	6
300	$3\frac{1}{4}$	6	5

The principles developed in the course of this Paper are, it is submitted, of very general importance; and there is no doubt that much, if not all of what has been here deduced, from experiment and observation with locomotive boilers, is applicable to boilers of every variety. This may form the subject of another communication; meantime, it may be useful to test some of the more conspicuous examples of locomotive boilers, by the principles here enunciated, many of which the Author believes he has been the first to announce to the engineering profession.

The early engine, the 'Hecla,' would raise, according to its grate and surface, just 47 feet of water per hour economically; whereas it was made to raise 94 feet, or double the economical amount, and this with a great sacrifice of fuel. To raise 94 feet economically, the 'Hecla' would have required, with the same grate, 590 feet of surface, or 172 feet more than it had. Or, without enlarging the surface, it would have economically raised 90 feet of water, by simply halving the grate-surface, and reducing it to a little more than 4 feet. Of course, this would have doubled the rate of evaporation per foot of grate, but the combustion, by greater economy, would have been raised, in a much smaller ratio, to less than one-fourth more, from 125 lbs. to 153 lbs. coke per foot of grate.

The 'Great Britain' has certainly abundance of surface, and if that surface was profitably arranged, it would, with the existing grate, economically evaporate 330 feet per hour, at the rate of 16 feet of water per foot of grate. As it is, this engine does not raise even 230 feet, or 11 feet per foot of grate, with economy. With a barrel 58 inches diameter and tubes 2 inches diameter, there is convenient space for only 210 tubes, or 93 tubes less than the actual number (See Fig. 2); and these, with the existing firebox, would economically raise only 173 feet per hour. This is all that can be done with the tubes, except by enlarging the diameter of the barrel, and in order to embrace 303 tubes conveniently, it would require to be 6½ feet diameter. However, the economical equivalent of reducing the grate supplies the desideratum, and a grate only two-thirds of the actual dimensions, or 14 feet area, with 210 tubes properly arranged in the present barrel, would, allowing for reduced firebox-surface, economically evaporate 250 feet of water per

hour, at the rate of 18 feet per foot of grate, or 20 feet more than were actually raised at the time of the experiments.

The 'Liverpool,' on Crampton's system, commonly supposed to be the successful rival of the 'Great Britain,' is inferior to the latter, in the arrangement of the boiler. The Author has not any knowledge of the performance of this engine, but it is clear, that what would be beneficial for the 'Great Britain,' would be still more so for the 'Liverpool.' Like her rival, she has 303 tubes, but they are packed into a smaller barrel, only $4\frac{1}{2}$ feet diameter, and with $\frac{7}{16}$ inch clearance. Half the number of tubes would have done more actual service, and if the grate also were cut down to one-half, the engine would undoubtedly be a more serviceable and more powerful machine.

Mr. McConnell's new engine is, on various accounts, still more defective than either of its gigantic compeers. In this engine the tubes are, as in the others, 303 in number, and therefore much too numerous, and to add to the defect, they are only 7 feet long. It was hoped, however, to compensate for the paucity of tube-surface, by projecting a large flue-tube into the barrel, as a continuation of the fire-box, precisely as in the modified Killingworth engine, made in 1830; and according to Stubbs' patent. This tube furnished its quota of what Mr. McConnell terms firebox-surface, though it may with equal propriety be denominated tube-surface. Its most important function, however, in the estimation of the designer, is to complete the combustion of the fuel, previously to entering the small tubes, and it is hence called the combustion-chamber; air-valves are fitted to the front of the fire-box, for suitably supplying air to mix with the gases. It has been shown, from recorded evidence, how little real distinction there is between firebox and tube-surface, and how necessary it is, that heating-surface should be freely extended, to give timely opportunity for the absorption of heat, before the hot gases leave the boiler. Allowing that all the heating-surface is economically arranged, which is not the case, this engine, with its limited surface of 1120 feet, and large grate of 23 feet, would evaporate, economically, only 120 feet of water per hour. Stephenson's long boiler, with but 900 feet of surface, and a grate of $9\frac{1}{2}$ feet,—less than half the size of the other,—is capable of economically evaporating 40 feet more than this, owing to its superior arrange-

ment. But it is said, that the new engine is expected to evaporate 260 feet of water per hour, for the due performance of its duty; now it is submitted, that the boiler is quite incapable of doing so, except at a heavy sacrifice of fuel, and accordingly the loss of heat by the chimney has been observed to be "prodigious." Further, the aids to combustion, provided in this boiler, in the roomy flue and the air-valves, are in practice unnecessary, as it has been shown, in a former part of this Paper, that the combustion of coke in the locomotive firebox is, under ordinary conditions, practically perfect.

The results as yet obtained from the new boiler have not been satisfactory, on the score of a deficiency of heating-surface; and it is at present being fitted with two additional diaphragms in the firebox. This boiler is not, however, likely to work satisfactorily as at present arranged. The combustion-chamber should be removed, the air-valves should be closed, the tubes should be extended up to the firebox, and be very much reduced in number, and the firebox should be reduced so as to have a grate of 16 feet area. In this way it would raise about 260 feet of water per hour, at the rate of 16 feet of water per foot of grate, and would do so easily and economically, according to the original requirements of the designer.

It is necessary, of course, in arranging a boiler, to take into consideration its influence on the area of the blast-orifice: as the orifice ought to be sufficiently wide to exhaust the steam freely, without back pressure. The link-motion is the only valve-gearing now employed in this country for locomotives, nor is it likely soon to be superseded, as, in simplicity, efficiency, and durability, it is unsurpassed, indeed unapproached, by any other form of gearing in present practice, for high-speed engines. The following recommendations, then, are made chiefly in connection with the use of the link-motion, while they may, it is expected, also be followed up, generally, with respect to other forms of valve-gear.

The Author's investigations on the subject of the blast-pipe, and its relations to the engine and the boiler, founded on direct experience, have been fully detailed in his work on Railway Machinery; and in this place it may suffice to quote the conclusions at which he has arrived.

When the cylinders and the steam-passages are perfectly

protected, with steam-ports one-tenth of the area of the piston, an inside lead of one-twelfth, and a blast orifice of one-tenth, or one-eleventh, the exhaust of steam from the cylinders is practically perfect, at all speeds of the piston, under 800 feet to 900 feet per minute, or 50 miles to 60 miles per hour, on the rails, as the exhaust back pressure constitutes even at the highest speeds and in full gear, but a small fraction of loss, of no importance in practice.

When the cylinders are imperfectly protected, or not protected at all, very heavy back pressure of exhaust arises at high speeds, even with an orifice as large as one-tenth of the piston, arising from the important condensation of steam in the cylinder.

The necessary area of blast-orifice is regulated by the dimensions of the boiler; it varies, chiefly, with the grate-area, and the sectional area of flue-way at the ferrules, and the tubes. It is regulated also, by the capacity of the smokebox, by the diameter of the chimney, and by the level of the orifice, with respect to the chimney.

Assuming the grate-area as unity, the capacity of the smokebox should be 3 cubic feet per foot of grate, and the sectional area of the chimney should be one-fifteenth of the grate-area; the blast orifice should be at a level below the crown of the smokebox, or the bottom of the chimney, equal to the diameter of the chimney. These ratios are the most conducive to the efficiency of the blast, and admit of the widest practicable orifice, consistent with the necessary steam-producing power.

In boilers of ordinary proportions, of which the ferrule-area of flue-way at the firebox is about one-fifth of the grate-area, and the tube-area one-fourth, and in which the best adjustment of smoke-box and chimney is effected, the area of blast-orifice may be made equal to one-sixty-sixth of the grate-area. With the most restricted flue-ways, when the ferrule-area may be as small as one-tenth of the grate, the orifice may be one-ninetieth of the grate.

From these data, it is easy to deduce the greatest size of piston, consistent with a free exhaust through the blast-orifice. The areas of pistons vary from $\frac{1}{12}$th to $\frac{1}{6}$th of the grate; then, for boilers of ordinary proportions, in which the orifice may be $\frac{1}{66}$th of the grate:—with pistons $\frac{1}{12}$th to $\frac{1}{6}$th of the grate,

the orifice may be $\frac{2}{11}$ths to $\frac{1}{11}$th of the piston; and for extraordinary boilers, as above defined, with pistons $\frac{1}{12}$th to $\frac{1}{6}$th of the grate, the orifice may be $\frac{2}{15}$ths to $\frac{1}{15}$th of the piston.

Thus, for ordinary boilers, even with the largest pistons in use, the orifice may be made large enough for free exhaust. But pistons so large as $\frac{1}{6}$th of the grate are extreme cases, and are found to be superfluously large; and an extreme ratio of $\frac{1}{8}$th may be considered abundantly wide in practice. Taking this view of the case, or at least assuming that for extraordinary boilers, larger pistons than one-eighth of the grate should not be employed, then, in the most unfavourable circumstances, the orifice need never be less than ($\frac{1}{90} \div 8$), or one-eleventh of the piston; and it follows generally, that in all practical cases, the blast-area may be made abundantly large enough for the requirements of free exhaustion.

This conclusion is of very great importance, as the blast-pipe has, at all times, been a matter of anxiety to locomotive engineers, in their endeavours to make it small enough to raise the necessary draught, and to generate a sufficiency of steam, and at the same time also wide enough to exhaust freely. The Author has, he believes, succeeded in furnishing a solution of the question, by analysing many different cases, and separating and combining the elements proved to be most influential in regulating the blast-area. Henceforth the blast-pipe should be a matter of easy adjustment, and need not enter into the calculations of the locomotive constructor; it need no longer be considered an extravagantly-wasteful stimulator of combustion, consuming, according to some English and American writers, one-half of the whole power of the engine; and leading to the adoption of inconveniently-large grates, numerous tubes, and short boilers. It has commonly been assumed, also, that the 13 feet, or 14 feet tubes of long boilers offer, on account of their extra length, a greatly-increased resistance to the draught, and require, on that account, an injuriously small blast-pipe. But by a comprehensive analysis of the causes of small blast-pipes, it has been demonstrated, in the course of the inquiries above referred to, that the objection of frictional surface has little practical weight,—that it is, indeed, the most insignificant of *all the* producing causes, and that, in long boilers, as in all *others*, the limiting causes are, the extent of grate-area, and the

sectional areas of flue-way. The practical ultimatum then is, that the boiler should be of sufficiently-extended proportions to afford a blast-area of at least one-eleventh of the piston. So long as an orifice of at least one-eleventh is attainable, one boiler may be as good as another, as it has been found that nothing can be gained by making it materially wider.

It remains, finally, to adjust the surfaces of the boiler, to the evaporative power required for working the trains, for which the boiler is designed. This leads to the question of train-resistances, the influence of gradients, &c.; and would involve a separate paper for the proper solution of the question. When the rate of consumption of water is given, the suitable proportions of the boiler are readily determinable, by means of the Rules, and by reference to the Tables contained in this Paper.

The second and third divisions into which the general subject was resolved, or the engine and the carriage sections of the locomotive, require independent investigation, before the problem of the locomotive, as a whole, can be satisfactorily solved. They may form the subjects of future communications.

Mr. CLARK referred to several examples, from the experience of Pambour and other experimentalists, to show that the fire-box surface was a matter of indifference, and in corroboration of the views propounded in the Paper generally. The inferiority, in evaporative power, of the 'Great Britain,' might be accounted for by the want of clearance, or space between the tubes, not allowing of the free exit of the steam. In the 'Great Britain' there were 303 tubes, with a clearance of $\frac{1}{2}$ inch; whilst in the Caledonian engine there were but 158 tubes, with a clearance of $\frac{5}{8}$ inch.

In reply to questions, Mr. Clark stated, that in his experiments he had weighed the total quantity of coal and coke used in getting up steam, and then what remained in the tender and in the fire-box after the engine had done running. He did not, in any case, make allowances; everything was the result of actual measurement.

Mr. HAWKSHAW said, if concentrated rapid combustion was essential in locomotives, how could small grates be recommended? Rapid combustion might be necessary to make the engine do much work, but it was wasteful of fuel. Slow combustion was more economical, though in locomotives the speed could not be thus attained. He would ask, whether it was possible to do so by restricting the fire-grate?

With regard to Mr. McConnell's engines, they might be fitted for speed, but he did not think they were calculated for economy. Though long boilers might absorb a larger quantity of the heat, before it reached the smoke-box, and lead to economy of fuel, this was not the only point for consideration.

Mr. T. R. CRAMPTON believed, that rapid combustion would be found the most economical in locomotive boilers. He had, for the purpose of experiment, increased the area of the fire-grate twofold, so as to have a thin fire and a slower draught, but without any advantage. He had, therefore, returned to the former dimensions, a heating surface of eighty-five to ninety times the grate-area. In the 'Liverpool' the area of the heating surface was one hundred times the grate-area, which he thought would be found a higher proportion than in any other engine. A practical rule, followed by some engineers, and founded on experience, was to allow 5 square feet of heating surface to evaporate 1 cubic foot of water per hour, and 112 lbs, or 1 cwt.

of fuel per foot of grate per hour. These results were found to agree with the maximum rates recommended in the Paper. He did not attach much importance to the position of the evaporative surface, whether it was fire-box, or flue-surface, believing that if the amounts were equal, the results would be identical.

Though the combustion in locomotive boilers might be too rapid for steam-boats, still he considered that marine engineers would not lose anything, if they studied railway practice; as higher powers were produced in locomotives than in any steam-vessels. The slower rate of combustion, however, tended to save the metal of the boiler.

Mr. Scott Russell remarked, that locomotives were worked more expansively than marine engines. In the latter the consumption of coal rarely now exceeded 6 lbs. per H. P. per hour.

Mr. R. Stephenson, M.P., V.P., said, the Author's views were so coincident with his own, that he could not refrain from offering a few remarks on the important questions which arose out of the Paper. With respect to simple combustion, there were two opinions extant. The prevailing one was, that the combustion of coke was imperfect in the locomotive. He did not now hold that view. He had discussed the subject fully with Professor Daniell, who considered, on the contrary, that the combustion in the locomotive was most complete. At a white heat it was found that nearly pure carbonic acid was generated. Mr. C. Wye Williams' experiments in introducing the air near to the bridge, created additional visible combustion in the flues, so that although there were clouds of dense smoke whilst the apertures were closed, on opening the holes the flue became illuminated. Still there was no marked economy of fuel, and the iron of the boiler was destroyed. If it were true that the quantity of heat developed in consuming carbon was in proportion to the oxygen brought in contact with it, then the admission of oxygen, within certain limits, should cause economy. He had never known more than 5 or 6 per cent. to be saved by smoke-preventing apparatus. He argued, therefore, that there was very little imperfect combustion. Unless the oxygen entered through the fire, in his opinion it did little good. He had tried the admission of air at various heights in the fire-box, without producing any good effect.

As to the comparison between slow and quick combustion, the

ultimate result in each case must be identical, if the combustion in both was perfect. The result of burning a pound of coke perfectly, must be the same under all circumstances. Whatever might be the arrangement of the boiler, if the coal was consumed, the heat absorbed, and the chimney kept cool, all the useful effect was got out of the fuel that could be obtained.

The Author's deductions, as to the practical identity of fire-box and tube surface, for evaporating action, must be admitted; and likewise the constancy of the evaporative efficiency of fuel, whether by radiant, or communicated heat, or both together, or whether the draught was mild, or strong. Heat was specific and certain in its effects, and could be dealt with like any ponderable body. Such expedients as 'midfeathers,' &c., which were resorted to for specially increasing the fire-box surface, must be condemned. They were inconvenient and costly, causing the space for fuel to be occupied by water; whilst plates of $\frac{7}{16}$ths, or $\frac{1}{2}$ inch in thickness, were employed to do the work of the tubes, which were less than $\frac{1}{8}$th inch in thickness, and were equally serviceable as heating surface.

In comparing the long with the short boiler experiments, it was important to know the rate of evaporation. For moderate speeds moderate firing might be practised, and short boilers might then be usefully employed. Long boilers might be better with heavy loads, and short boilers with light loads. In the gauge experiments, an engine with the smallest fire-box ever made, and having 80 tons attached to it, working to her highest power, evaporated from 150 cubic feet to 170 cubic feet, at the rate of 9·1 lbs. of water per pound of coke. That great economy was obtained under the best circumstances, and by utilizing the power of the engine to the utmost. If the load had been smaller the good qualities of the engine would have been less apparent.

Mr. J. Field said, as the Author of the Paper had given the proportions and evaporative powers of the best locomotive boilers, it was desirable that a comparison should be instituted between them, and the best tubular marine boilers, now used in ocean navigation. The general features of the boilers in both cases were nearly identical, but the circumstances under which they were used were very different. In marine boilers, coal was used instead of coke, and the natural draught of the chimney sufficed, instead of employing the blast-pipe, as in a locomotive. Salt

water was also used, instead of fresh water, and a pressure of about 12 lbs. or 14 lbs., instead of from 60 lbs. to 80 lbs. on the square inch. Although lightness and compactness were important properties in marine boilers, they were less so than in locomotives, and the former were frequently worked for many weeks, or months consecutively, without the opportunity of stopping for any extensive repair, or even for cleaning, except at long intervals. Under these circumstances marine boilers required to be worked less intensely, and the water and flue spaces must of necessity be larger, to prevent their being choked up.

The following statement showed the comparative proportions and effect of the two descriptions of boilers:—

In the Locomotive Boiler.	In the Marine Boiler.
1 square foot of fire-grate consumed about 112 lbs. of coke per hour.	1 square foot of fire-grate consumed about 20 lbs. of coal per hour.
1 square foot of fire-grate required about 85 square feet of fire-box and tube surface.	1 square foot of fire-grate required about 30 square feet of fireplace and tube surface.
1 square foot of fire-grate with the above surface, would evaporate 1008 lbs. of water per hour.	1 square foot of fire-grate with the above surface would evaporate 170 lbs. of water per hour.
1 square foot of flue surface would evaporate 11·7 lbs. of water, per hour.	1 square foot of flue surface would evaporate 5·66 lbs. of water per hour.
1 lb. of coke would evaporate 9lbs. of water.	1 lb. of coal would evaporate 8·5 lbs. of water.
1 H. P. of 33,000 lbs. raised 1 foot high per minute, required about 4 lbs. of coke per hour.	1 H. P. of 33,000 lbs. raised 1 foot high per minute, required about 4·25 lbs. of coal per hour.

From this statement it appeared, that although the proportion between the fire-grate and the flue surfaces was widely different, the quantity of water evaporated, and the power obtained, by the consumption of a given weight of fuel, were nearly the same, when allowance was made for the difference in the evaporative powers of coal and coke.

Mr. McConnell contended, that the formula, as stated in the Paper, would not apply to all engines. The following table of the actual working results of engines, compared with deductions from the formula, exhibited in some cases a greater, and in others a less rate of evaporation of water, and consumption of coke, per square foot of grate surface per hour, than the formula would have given:—

ACTUAL WORKING RESULTS of ENGINES, compared with Deductions from the Formula.

Name or Number of Engine.	Total Heating Surface.	Total Fire-grate Surface.	Number of Carriages.	Speed per Hour.	Actual Evaporation per Square Foot per Hour.	Evaporation by Mr. Clark's Formula.	Actual Coke Consumption per Square Foot per Hour.	Coke Consumption by Mr. Clark's Formula.	Per Centage of Difference in Water.	Per Centage of Difference in Coke.	Date, and Name of Observer.
234	1125	14·32	12·3	26·5	5·41	16·05	44·9	126·3	180	188	From March 10th to 12th, both inclusive— Mr. Alexander.
291 1st Experiment	1325·8	18·8	9	42·1	4·72	11·04	40·8	116·5	175	190	24 February— Mr. Forsyth.
291 2nd Experiment	1325·8	18·8	17	38	5·12	11·04	58·43	102·7	120	76	7 March— Mr. Alexander.
300	1133·21	23·5	34	36·4	8·21	5·16	65·5	40·37	60	62	8 March— Mr. Forsyth.
Rocket— 1st Experiment	707	10·6	9	42·1	8·99	9·89	78·4	86·2	12	10	24 February— Mr Alexander.
Rocket— 2nd Experiment	707	10·6	13	34·5	11·9	9·89	102·3	84·4	22	21	25 February— Mr. Alexander.
Heron & Prince of Wales	707·54	10·6	34	34·5	10·68	9·89	72·1	73·7	11	10	8 March— Mr. Alexander.

It would be seen, that in no case did the results deduced from the formula accord, entirely, with the practical results given in the table; the nearest approximation was that of the 'Rocket.' Further, Mr. McConnell argued, that from various causes, no formula could be framed to be of service, unless all the circumstances, in each case, were taken properly into account.

As an example of the objections to long tubes, Mr. McConnell gave the results of the work done by a luggage engine (No. 125) on the London and North-Western Railway, before, and after alteration. That engine originally had tubes 14 feet long, with a total surface of upwards of 800 feet. The length of the tubes was diminished to 4 feet 9 inches, and the total surface was reduced to about 500 feet, when it was found, that a saving in fuel of 40 per cent., per ton per mile run, was produced, with a saving of 23 per cent. per mile run. The coke used, per ton per mile, with long tubes, before alteration, was ·504 lb., and with the short tubes ·298 lb. In the altered goods-engine, two or three midfeathers had now been substituted for the horizontal transverse water tubes, from which certain practical inconveniences had been found to arise.

The back pressure was a serious objection to the long-tube engine. In a trial of a single engine, on the new plan, against two of the ordinary kind, with a load of 170 tons, in both cases, the former ran the same distance of 111 miles, in ten minutes less time than the latter, and with 3 lbs. per mile less fuel. The single engine in this case was 43 per cent. less powerful, than the two engines together, and had 20 per cent. less heating surface. This, he argued, was owing to the engine exerting a greater dynamic force, by being relieved from the back pressure of the blast-pipe, which in the case of the other two was applied to force the fire, and to draw the heated air through the long tubes.

By the mode of placing the tube plate some distance within the cylindrical part of the boiler, the tubes were not liable to be choked with cinders, or the draught to be obstructed. This plan also afforded an opportunity of reducing the size of the tubes from $1\frac{3}{4}$ inch diameter, to $1\frac{5}{8}$ inch, giving, in the same boiler, an equal area of flue passage, whilst, at the same time, the proportion of tube heating surface was increased 34 per cent., per foot of length of tube, and a very large addition of flame surface was gained.

Although the evaporation of water per lb. of fuel, was the test of the boiler, yet, up to this time, few, if any, experiments could be implicitly relied upon, owing to the quantities being estimated by measurement, instead of by weight, and without due regard to the variation of the temperature of the water in the tender.

It had been found, that intense combustion was liable to cause the formation of clinkers in the small fire-box, but which did not occur in the new engine. When the drivers first took out the new engine, being unaccustomed to its peculiar action, they kept thin fires, and drew too much air through the fuel, which was wasted, by raising steam too freely; latterly, the fires had been kept thicker, and the combustion had been slower, whilst the supply of steam had been fully equal to all demands upon the engine. It should be recollected that this engine had been built expressly for conveying heavy loads at high speeds. Its performances, so far, under these circumstances, must, he contended, be classed among the best recorded results of the present day. If it had been compatible with the regulations of the Institution, he would have proposed a comparative trial of this new class of engine, with an engine of any other class, upon any railway in the kingdom; or even against any two engines combined, provided that their united heating surface did not exceed, by more than 20 per cent., that of the new class of engine. The conditions of the trial, he would have proposed, would be:—that the weight of the trains should not be less than 125 tons, exclusive of the engine and tender;—that the speed should not be less than 36 miles per hour, exclusive of stoppages; or a load of 200 tons at the same speed;—and that the tests of merit should be,—the comparative consumption of fuel per ton per mile, and the time of the performance of the duty.

Mr. Bidder said, his views were so much at variance with the results recorded in the Table of "Actual Working Results, &c.," and the inferences drawn therefrom, that he thought it might be useful if he were to attempt an impartial analysis of what had been advanced.

It was essential in questions of this kind, that all the attending circumstances should be fully explained. It was alike important to know the state of the weather, the condition of the road, the actual quantity of coke consumed, and of water evaporated. The *consumption* of water could be arrived at with some degree of

accuracy, if not indeed with the greatest nicety, as it might be gauged when the engine was at rest, before starting, and after it had arrived at the end of the journey. He was inclined to doubt, whether the consumption of coke could be arrived at with the same amount of exactness. It was evident, from the Table of the "Actual Working Results, &c.," that, on this point, the formula had been misunderstood and wrongly applied. For instance, in the two experiments with the 'Rocket,' the consumption of coke deduced from the formula, was stated to be 86·2 lbs. and 84·4 lbs. per square foot of grate per hour; and in the 'Heron' and 'Prince of Wales,' which were of nearly identical proportions, the calculated consumption of coke was given as 73·7 lbs. per square foot of grate per hour, whereas in all three cases the amount should have been the same. Again in the two experiments with No. 291 engine, a similar discrepancy was apparent, the calculated consumption being given as 116·5 lbs. and 102·7 lbs. per square foot of grate per hour. In the experiments themselves, there were several unexplained anomalies, and in some instances, the engines were performing very inadequate duty, and therefore under circumstances to which the formula was not intended to apply.

In the case of the altered luggage engine, No. 125, it was clear that, in its original state, the engine must have been, either in a very inefficient condition, or that its duty must have been chiefly confined to piloting, when it would have been consuming the fuel, without producing any useful effect; as a consumption of 58 lbs. per mile run, with an average train of 115 tons, was out of all proportion. Mr. Bidder considered that the result of the working, after the alteration, was not favourable, as with a load of 144 tons, the consumption of fuel was 43 lbs. per mile run, whereas a narrow-gauge engine, reported on by Mr. D. Gooch, in the Gauge Inquiry, with a load of 294 tons, had only a consumption of 47 lbs. per mile run. Also, when compared with the working of the Eastern Counties goods-engines, for the last half year, where, with an average load exceeding 170 tons, the consumption of coke was only 32 lbs. per mile, taken over a distance of 529,000 miles.

A comparison of the recent experiments, by Messrs. Woods and Marshall, on the large fire-box engine, with those on the long-boiler engine, made during the Gauge Inquiry, showed, with

Although the evaporation of water per lb. of fuel, was the test of the boiler, yet, up to this time, few, if any, experiments could be implicitly relied upon, owing to the quantities being estimated by measurement, instead of by weight, and without due regard to the variation of the temperature of the water in the tender.

It had been found, that intense combustion was liable to cause the formation of clinkers in the small fire-box, but which did not occur in the new engine. When the drivers first took out the new engine, being unaccustomed to its peculiar action, they kept thin fires, and drew too much air through the fuel, which was wasted, by raising steam too freely; latterly, the fires had been kept thicker, and the combustion had been slower, whilst the supply of steam had been fully equal to all demands upon the engine. It should be recollected that this engine had been built expressly for conveying heavy loads at high speeds. Its performances, so far, under these circumstances, must, he contended, be classed among the best recorded results of the present day. If it had been compatible with the regulations of the Institution, he would have proposed a comparative trial of this new class of engine, with an engine of any other class, upon any railway in the kingdom; or even against any two engines combined, provided that their united heating surface did not exceed, by more than 20 per cent., that of the new class of engine. The conditions of the trial, he would have proposed, would be:—that the weight of the trains should not be less than 125 tons, exclusive of the engine and tender;—that the speed should not be less than 36 miles per hour, exclusive of stoppages; or a load of 200 tons at the same speed;—and that the tests of merit should be,—the comparative consumption of fuel per ton per mile, and the time of the performance of the duty.

Mr. BIDDER said, his views were so much at variance with the results recorded in the Table of "Actual Working Results, &c.," and the inferences drawn therefrom, that he thought it might be useful if he were to attempt an impartial analysis of what had been advanced.

It was essential in questions of this kind, that all the attending circumstances should be fully explained. It was alike important to know the state of the weather, the condition of the road, the actual quantity of coke consumed, and of water evaporated. The *consumption* of water could be arrived at with some degree of

accuracy, if not indeed with the greatest nicety, as it might be gauged when the engine was at rest, before starting, and after it had arrived at the end of the journey. He was inclined to doubt, whether the consumption of coke could be arrived at with the same amount of exactness. It was evident, from the Table of the "Actual Working Results, &c.," that, on this point, the formula had been misunderstood and wrongly applied. For instance, in the two experiments with the 'Rocket,' the consumption of coke deduced from the formula, was stated to be 86·2 lbs. and 84·4 lbs. per square foot of grate per hour; and in the 'Heron' and 'Prince of Wales,' which were of nearly identical proportions, the calculated consumption of coke was given as 73·7 lbs. per square foot of grate per hour, whereas in all three cases the amount should have been the same. Again in the two experiments with No. 291 engine, a similar discrepancy was apparent, the calculated consumption being given as 116·5 lbs. and 102·7 lbs. per square foot of grate per hour. In the experiments themselves, there were several unexplained anomalies, and in some instances, the engines were performing very inadequate duty, and therefore under circumstances to which the formula was not intended to apply.

In the case of the altered luggage engine, No. 125, it was clear that, in its original state, the engine must have been, either in a very inefficient condition, or that its duty must have been chiefly confined to piloting, when it would have been consuming the fuel, without producing any useful effect; as a consumption of 58 lbs. per mile run, with an average train of 115 tons, was out of all proportion. Mr. Bidder considered that the result of the working, after the alteration, was not favourable, as with a load of 144 tons, the consumption of fuel was 43 lbs. per mile run, whereas a narrow-gauge engine, reported on by Mr. D. Gooch, in the Gauge Inquiry, with a load of 294 tons, had only a consumption of 47 lbs. per mile run. Also, when compared with the working of the Eastern Counties goods-engines, for the last half year, where, with an average load exceeding 170 tons, the consumption of coke was only 32 lbs. per mile, taken over a distance of 529,000 miles.

A comparison of the recent experiments, by Messrs. Woods and Marshall, on the large fire-box engine, with those on the long-boiler engine, made during the Gauge Inquiry, showed, with

the former, a consumption of 40 lbs. per mile, with an average load of 64 tons, and with the latter, a consumption of 27 lbs. per mile, with a load of nearly 60 tons. The recorded results of the work of the passenger trains, on the Eastern Counties Railway, for the last half year, showed an average consumption of coke of under 18 lbs. per mile run.

Mr. Bidder contended, that hitherto, no advantages had resulted from the extension of the fire-box, and the reduction of the length of the tubes, in the new engine. It was possible, that this innovation might, by directing attention to the subject, lead to important modifications in the structure of locomotive boilers. The present object, however, was to consider what were the requisites for the best form. It should possess compactness,—lightness,—power of raising sufficient steam, with rapidity, for performing the required work,—strength to resist the chance of explosions, and a construction adapted to diminish the disastrous effects of such accidents, when they occurred,—together with facility of repair. The latter point was especially necessary with the fire-box, which was the part most subject to deterioration, and was most severely acted on by the fire. It also required more support than the tubes, which were at the same time, cheaper and of thinner metal. By extending the length of the tubes, the diameter of the external shell of the boiler could be diminished; it would thus be stronger, and be less liable to explode. The fire-grate should not be larger, than would evaporate the required quantity of water into steam, within a given time, with the utmost practical economy of fuel. If that were accomplished, it was of little importance whether the evaporating heat was communicated through the fire-box, or by the tube surface. The tubes should be long enough to abstract all the heat; as the measure of effective working, was the difference of the temperature in the fire-box, and that in the chimney. As to the mid-feathers, they had, hitherto, only served to extend the dimensions of the fire-box and fire-grate, and so far to increase the difficulties of maintenance and repair. Although something might have been gained by the space between the fire-box and the tubes, for the cinders to be collected in, he considered that, on the whole, up to the present time, the results of the experiments, upon the boiler with enlarged fire-box and shortened tubes, exhibited rather a retrograde step, than an onward progressive movement.

Mr. Clark explained, that he had arrived at the conclusion, that 1 lb. of carbon, completely burnt with oxygen, was capable of evaporating 12 lbs. of water into steam, in the following manner. The mean of several observations, all nearly equal, made by leading experimentalists, gave 14,000 units of heat,[1] as the heat evolved by 1 lb. of carbon converted into carbonic acid. As the ordinary temperature of water delivered to the tenders of locomotives was 60°, and the total heat of steam of 120 lbs. was 1221°, it followed that there was an absorption of 1161°, which was equivalent to the conversion of 12 lbs. of water at 60°, into steam of 120 lbs., by 1 lb. of carbon. The temperature in the tender might certainly be raised by blowing back the waste steam from the boiler; but this did not affect the whole evaporative duty of the coke.

He then proceeded to show, that his formula was derived directly from the tabulated results, and that, at least, it was substantially correct for rates of evaporation from 6 to 18 cubic feet of water per foot of grate per hour. The formula was deduced by means of a base line, and a curve drawn to pass through the rates of economical evaporation, indicated by stars: this curve, in its development, was parabolic, and he had, therefore, adopted its algebraic expression—

$$c' = \cdot 00222 \left(\frac{h}{g}\right)^2$$

as embracing the whole of the results. In this formula c' was the economical evaporative power in cubic feet of water per foot of grate per hour; h, the total inside heating surface, and g, the grate area, both in square feet. By multiplying both sides by g, he obtained

$$c = \cdot 00222 \frac{h^2}{g}$$

in which c was the total economical evaporative power per hour, in cubic feet of water.

The formula was not intended to express, unconditionally, the limits of the evaporative power of locomotive boilers, but only the maximum evaporative power, consistent with economy of fuel; the assumed standard of economy being the evaporation of 9 lbs. of water per pound of coke. The rate of evaporation

[1] A unit of heat is here understood to signify that which raises the temperature of 1 lb. of water through 1 degree Fahrenheit.—Ed.

might be, no doubt, as it often was, forced up beyond the economical limit, but only by an extra waste of fuel.

With respect to the greater time occupied by the Crewe engines on the trial, Mr. Clark considered that this was due, not to any defect in the boilers, but to the exposed position and unprotected state of the cylinders, by which steam was condensed. The chimneys were also too large in diameter; had they been 12 inches, instead of 15 inches, and had the orifice of the blast pipe been lower, the results, with the same boilers, would have been better.

According to the results of eighteen experiments with the new boiler, conducted by Mr. W. P. Marshall, it appeared that an average of 150 cubic feet of water per hour, had been evaporated, at a rate of only 7½ lbs. of water per pound of coke, or at a sacrifice of one-fourth of the duty of the fuel, according to the economical standard. Now the formula indicated that the new boiler could not, economically, evaporate above 120 cubic feet of water per hour; and the correctness of this indication was confirmed by the result.

With regard to the facility of getting up steam in the new form of boiler, and which was attributed to the free draught, Mr. Clark stated, that in the year 1829, the 'Rocket,' the first tube-boiler engine ever made, got up the steam from cold water in 57 minutes, whilst the new form of boiler required 86 minutes. This, however, was a point to which he did not attach much importance. The benefit of the removal of the tube-ends, in the new boiler, from the direct action of the fire, was more than balanced, by the liability of the lower part of the combustion-chamber to become over-heated, and be burned away, owing to the lodging of steam, at the junction with the fire-box.

In conclusion, Mr. Clark suggested, that in order to obtain better results from the new engine, the combustion-chamber should be abolished, the number of the tubes should be reduced, and their length be extended to the fire-box, and that the grate area should be restricted to 16 square feet; by which the engine would be qualified for the duty of evaporating, economically, 260 cubic feet of water per hour, or more than double what it could do in its existing form.

Mr. T. R. Crampton believed, that the best form of boiler

would never be arrived at by experiments conducted with running trains. There were too many contingent circumstances affecting the result. He would suggest that the water should be evaporated when the engine was standing still; and that after determining this point, then the amount of fuel necessary for conveying a given load might perhaps be ascertained.

Mr. HAWKSHAW observed, that a locomotive boiler at rest, and one in vibratory motion, were not in precisely similar conditions. There was much danger in instituting comparisons from different series of partial experiments. Some trials which he had made, in 1838, with an engine on the Lancashire and Yorkshire Railway, led to the conclusion, that, at fast speeds, the consumption of coke to 1 cubic foot of water was 8·96 lbs. and 9·30 lbs. At a velocity of twenty miles per hour, it was only 7·76 lbs., thus showing that there was an undoubted economy in that engine at slow speeds. A similar series of trials twelve years later, in 1850, on the same railway, showed that with the goods' engines, the consumption of coke was 8·12 lbs. per cubic foot of water evaporated; whilst with the passenger engines it was 7·3 lbs. It would thus be seen, that there was no great improvement, during that period, in the evaporative powers of the boilers. They were now worked at higher pressures, and to do this with safety, thicker plates were used. With regard to the statement, that shortening the tubes, and introducing the novel form of fire-box, caused a reduction in the consumption of fuel, he considered that this did not tend to prove the advantage of the system. The saving of a small quantity of coke was, after all, not the main question. It was important to know what would be the comparative cost of repairs; and, in this respect, he thought the new engine would be much more expensive, and that the midfeathers would render continual repairs necessary.

Mr. PHIPPS thought that the point to be aimed at was to obtain the most perfect combustion of the fuel. If that were done more completely in the new engine than in others, then it might be an improvement. In the early competitive trials at Liverpool, the 'Rocket' and 'Novelty,' although very dissimilar in details, were built with the same objects as those sought to be attained in the new engine.

Captain W. S. MOORSOM thought that the steam raised in the new boiler would be purer than in ordinary boilers. He feared

that the boilers in ordinary practice were a little too small for the tube surface; the fire-boxes had also, by degrees, become somewhat too small. In some experiments on the South Devon line, where there were heavy gradients, a train of four, or five carriages, with the engine pulling with a tractive force of 4000 lbs., was propelled at the rate of 25 miles per hour, with a consumption of 22 lbs. of coke. On the Bristol and Exeter Railway, a train, with the engine pulling with a tractive force of 2000 lbs., was propelled at the rate of 45 miles per hour, with an expenditure of 30 lbs. of coke. No doubt there were circumstances which would account for these different results. All engineers, and other observers, should be careful to accompany any statement of the results of experiments, with a full record of all the facts of the case.

Mr. P. M. Parsons said, that the possible maximum evaporative efficiency of 1 lb. of coke had been stated at 12 lbs. of water, whilst according to experiments with the best boilers, it did not appear as yet to have exceeded 9 lbs. From this it resulted that they were 3 lbs., or 25 per cent., short of the ultimate effect. In assigning proportions between the area of the fire-grate and the heating surface, the depth of the fuel had not been considered. He believed that if the depth of the fuel were multiplied by the area of the fire-grate in locomotive and in marine boilers, the results would be nearly the same.

Mr. Crampton remarked that the thickness of the fuel was determined by the practice of the enginemen. It depended upon the quantity of air passing through the grate.

Mr. C. May urged that it was of the utmost importance, that an analysis should be made of the gases in the smoke-box, as a means of ascertaining whether the waste of carbonic oxide was most affected by slow, or by rapid combustion, or with long, or short tubes. There was reason to apprehend, that with a thick fire, the carbonic acid, passing through the fuel, conveyed away, wastefully, a large portion of the, otherwise useful, carbon.

Mr. McConnell said, it was not to be supposed, that the proportions of the new boiler were perfect, or that the results already obtained, were as good as could be expected. Still he was prepared to try a long-boiler engine, the tubes of which he had reduced 7 feet, and which had the improved combustion-chamber, against any one, or two other engines of the same

maker. He considered that at least 20 per cent. of fuel was wasted by the carbonic oxide passing off by the chimney. The Ebbw Vale Iron Company saved a large quantity of fuel, by collecting the carbonic oxide from the coking furnaces, and using it for calcining the mine and lime, and for raising steam, &c. The mere evaporation of water was considered to be a fallacious test. In the 'Heron,' owing to the smallness of the heating surface, the experiments were commenced with the water in the tender at a high temperature; this had vitiated the truth of the result, as the difference of bulk, due to the temperature of the water, had not been taken into consideration. The pressures in the boilers of the two engines, in the trial against the new engine, had not been noticed, but he presumed they were worked up to as high a pressure as they would bear.

Mr. BIDDER said, he must repeat his previously expressed opinion, that to enable a correct opinion to be formed, all the circumstances of the experiments should have been given. He had analysed the statements given in the table of "Actual Working Results, &c." and had shown them to be deficient in accuracy. It was not enough to suppose the two engines to have done their best, the absolute pressures should have been given.

Mr. D. K. CLARK argued, that the proof of the practically complete combustion of coke in the fire-box, founded on the observed evaporative performance of the fuel, and the heat-properties of the gases of combustion, was as valid, and certain, as any that could be derived from a chemical analysis of the gases.

The expansion of the water in the tender, when steam was blown back, would never, in his opinion, amount to more than one-half per cent. at 90°, of the volume at 60°, and about one per cent. at 120°. It was, therefore, practically unimportant. The measurement by volume, of the water in the tender, might, consequently, be relied on, at all ordinary temperatures. As to the fluctuations of the water in the tender, while the measurements were being made, he believed that the mean level might be closely approximated to, by observing the extent of the fluctuations, and that the average of a great number of such observations must be substantially correct.

With regard to marine and stationary boilers, he had not

2 F 2

asserted that the formula, as it stood, would apply; but he believed, that an adjustment of the co-efficient was all that was necessary, to render it capable of this extended application. He wished it to be particularly understood, that in the construction of the formula, he did not insist on one proportion of surface to grate, more than on another. A heavier boiler might work as economically as a lighter one; but inasmuch as it was heavier, it was clearly inferior, as it was desirable to combine compactness, lightness, and power, in locomotive engines.

If, as had been asserted, 20 per cent. of the coke passed off as carbonic oxide, the evaporation, with ordinary boilers, could not exceed 7·2 lbs. of water, per pound of coke; and in Mr. McConnell's new Express engines, where the temperature in the smoke-box was said to be from 1100° to 1200° Fahr., the evaporation could not exceed 5 lbs. of water, per pound of coke. These conclusions were, however, so at variance with the best-ascertained facts, that the hypothesis must be incorrect. Though the evaporative performance of coke, in locomotive boilers, was liable to be vitiated by priming, the results given in the Paper, were checked by the measurement of the steam passing through the cylinders, thus showing, by comparison with the water consumed from the tender, that there had been no material amount of priming.

He then referred to a recent experiment with an engine on the Caledonian Railway, in which the area of the grate was reduced by brickwork from 10½ square feet to 9 square feet. It was found, that while an engine of the same class (with 10½ square feet of grate surface) evaporated 122 cubic feet of water per hour, at the rate of 6·8 lbs. per pound of coke, the engine with the grate reduced to 9 feet, evaporated 132 cubic feet per hour, at the rate of 8 lbs. per pound of coke; showing that the smaller grate raised more water per hour, and evaporated a greater quantity per pound of coke.

Throughout the discussion, the formula and the reasoning in the Paper had been the chief points touched upon. But it was satisfactory to him that not one of the whole mass of facts he had accumulated, nor the deductions from them, had been fairly impugned. The qualities of the engine had been constantly mixed up with those of the boiler; whereas the Paper treated of boilers, exclusively. Now unless the boiler and

engine were carefully distinguished, the peculiar necessities and qualifications of each for efficiency could not be determined. The conditions of excellence should be found first, for the boiler, secondly, for the engine, thirdly, for the carriage, and lastly, the final duty would be to harmonise and adjust the respective conditions, for the efficient action of those elements, so as to produce the best joint result. Unless such a progressive course of investigation were followed, it was considered impossible to arrive at a final satisfactory conclusion. It was his desire, on subsequent occasions, to follow up the course of this inquiry.

Dr. Lyon Playfair said, that the question under discussion must be resolved by experiment, as it was not yet in a condition to be closely examined by chemical theory. It was no doubt true that the carbonic acid,—the normal product of combustion,—did seize an equivalent of carbon, from the incandescent coal, or coke, and took it away, as carbonic oxide, in which form no available heat was developed. If this carbonic oxide could be advantageously used, it would doubtless be productive of economy of fuel. But the practical question rested on other grounds. There was still a wide difference between the theoretical calculations of chemists, and the practical results arrived at by engineers. Thus, one pound of coal was supposed, theoretically, to be capable of raising 10 or 12 millions of pounds of water, one foot in height; whereas the results of the best Cornish engines, showed the practical effect to be only about 1 million pounds. Again, by theory, one pound of coal should evaporate nearly 14 lbs. of water, whilst practically, under favourable circumstances, only about 11 lbs. were evaporated. Whilst this discrepancy between theory and practice existed, it was useless to examine the question otherwise than practically.

Mr. P. M. Parsons, through the Secretary, said, he believed the question of the economical use of steam in the locomotive engine afforded a wider field for increasing the efficiency and economy of the machine, as a whole, than by confining the discussion to the boiler alone. Mr. Parsons thought that the expansive action of steam had, as yet, been applied in a very partial and disadvantageous manner to locomotive engines. The steam was either worked with its full pressure throughout the entire stroke, or nearly so, or it was worked expansively, to a limited extent, by the common D valve and ordinary link motion, or, in

a more extended and perfect manner, by means of a separate expansive valve and gear; but in all cases the driver had to accommodate the rate of expansion to the work the engine had to perform. When the engine was exerting its greatest power, and using probably twice, or three times the quantity of steam that it did when exerting its least, the steam was not worked expansively. It was only when the engine was exerting a less power, that any advantage from expansion was obtained. He considered that increased economy would result from substituting larger cylinders for those usually employed, and fitting them with an expansive apparatus, giving a fixed rate of expansion at all times. These conclusions had been arrived at by observing the working of several engines, under various circumstances, both with and without variable expansive gear. He found that the fixed expansive gear was about 21 per cent. inferior to the variable expansive gear, when the engine was doing a small amount of duty; but when that duty was doubled, the fixed expansive gear had an advantage of about 36·77 per cent., and that its superiority was in proportion to the increased duty and the higher pressure of steam used.

A simple method of applying a fixed expansive apparatus to cylinders placed together, with their slides back to back, was to add two cut-off valves, on the backs of the ordinary D valves, and to connect the expansive valve of one engine with the D valve of the other, and *vice versâ*. It would then be found, that the D valves, being adjusted so as to open and shut the steam and exhaust ports in the most advantageous manner, without expansion, the expansion valves would cut off the steam at $\frac{1}{5}$, $\frac{1}{4}$, or $\frac{1}{3}$ of the stroke, according to the adjustment, the one by its inner, the other by its outer edges, in reversing. The back eccentrics should be adjusted to cut off the steam by the D slides at about half stroke, as the expansion valves did not then come into play.

Mr. R. Stephenson, M.P., V.P., explained, that the Institution of Civil Engineers could not, by its regulations, take the initiative in any trials, but if the results were submitted to a meeting, they would doubtless undergo that candid consideration, and fair discussion, which all questions had hitherto received. Many of the results, already attained, were new and strange, and receiving them as facts, they induced careful re-consideration of previous impressions and accepted data, and from the attention

thus directed to a most important subject great results might be anticipated. The profession was greatly indebted both to the Author of the original Paper, for the clear and definite views he had laid down, and to the designer of the new boiler and engine, for the statement of the results which had been produced. He hoped that they would both continue their observations, and again meet in the Institution, for the comparison and discussion of the results.

Indicator Card for ascertaining the Pressure on the Piston of a Steam Engine.

After the meeting, Mr. Hulford, of H.M. Dockyard, Woolwich, exhibited an instrument of his invention, for ascertaining from an indicator card, the steam pressure on the piston of a steam engine.

The indicator card being placed on the board, so that the atmospheric line coincided with the marks on the retaining springs, the triangular scale was placed at the bottom of the figure, and the side roller made to revolve, until the spiral line on it intersected the edge of the scale, in which position the roller was fixed. The distances between the steam and vacuum lines were taken, by sliding the scale along the figure, and ten, or twenty divisions might be taken, according to the degree of accuracy required; the sum of the distances, divided by their number, gave the mean pressure on the piston.

A great saving of time, in the measurement of all irregular figures, resulted from the use of the instrument, and its simplicity and low price were also points in its favour.

March 15 and 22, 1853.

ROBERT STEPHENSON, M.P., Vice-President, in the Chair.

The discussion upon the Paper No. 887, "Experimental Investigation of the Principles of the Boilers of Locomotive Engines," by Mr. D. K. Clark, having been renewed, was continued to such a length as to preclude the reading of any communication.

April 5, 1853.

ROBERT STEPHENSON, M.P., Vice-President, in the Chair.

The following candidates were balloted for and duly elected:—Terence Flanagan, as a Member; Joseph Augustus Clarke, Thomas Minchin Goodeve, Henry Maxwell Lefroy, and Thomas Wright, as Associates.

No. 891. "On Locomotive Boilers and on Fuels."

By John Sewell.[1]

The subject of locomotive economy naturally divides itself into three distinct processes:—First, the production of heat; second, the generation of steam; and, third, the employment of steam.

These processes may be either wholly, or partially independent of each other. For stationary engines they are all nearly independent, but for locomotives they are only partially so, as in the latter the steam aids in generating heat, and the central position of the cylinders is affected by the boiler.

The two first processes of generating heat and steam, are however, more strictly the duty of the boiler, and may be considered together.

A cubic foot of water requires an equal amount of heat to convert it into steam, of an equal temperature, in any boiler, whatever be its form, or proportion; and it is somewhat remarkable, that the variations of steaming economy of stationary, marine, and locomotive boilers, only vary within nearly the same range as the different fuels in the same boiler, or to the extent of about twenty per cent. of the theoretical value.

The object of a good boiler is to effect the most complete combustion of the fuel, and to transmit the caloric so evolved sufficiently to the water. To realize these two points, numerous forms have been designed, and various rates of combustion have been tried, both in stationary and locomotive boilers. Space, or weight rarely interferes in designing stationary boilers, but for either marine or locomotive boilers, lightness and economy of space are essential.

[1] The Author has since been elected Assoc. Inst. C. E.

The early marine and common road steam-engineers adopted the principle of dividing the water by small tubes, whereby lightness was obtained; and the strength was such, that pressures of 250 lbs. to 300 lbs. per square inch could be, and were used.

Railway engineers have adopted the principle of dividing the heat by small tubes, which leaves the elastic force of the boiling water and steam in one mass, and requires a strong case to confine it. The safe pressure is, therefore, limited to about 100 lbs. or 150 lbs. in the common locomotive boiler as now made.

Historically this form of boiler embraces the Egyptian cylindrical boiler, with its internal hot-air chamber and hot-air blast on the fire, as illustrated by Hero, of Alexandria, Papin's tubular flue, Allen's fire-box of 1730, and Brindley's copper flues of 1756, as arranged by Stephenson in 1829.

In testing the comparative economy of different boilers, it is desirable to keep in view the different steaming powers of different fuels in the same boiler. For this purpose an example is given of the efficiency of each of the best Welsh, Newcastle, Lancashire, and Scotch coals, with one of Tanfield coke, as carefully tried in a small Cornish boiler, 12 feet long, and 4 feet diameter, with an internal flue of 2 feet 6 inches diameter, split at the back into two side flues, which joined at the front and returned below the boiler to the chimney.[1] Taking the heating value of 1 lb. of hydrogen as 62,470° Fahrenheit, and of 1 lb. of carbon as 13,268° Fahrenheit, the heating value of the above fuels are—

Class of Coal.	Name of Fuel.	Carbon.	Hydrogen.	Heating Value.
		Per Cent.	Per Cent.	Deg. Fah.
Welsh . .	Aberaman . .	90·94	4·28	14662
Newcastle	Tanfield . .	85·58	5·31	14671
Lancashire	Ince-Hall . .	82·61	5·86	14621
Scotch . .	Elgin . . .	76·09	5·22	13356
Carbon or	Pure Coke . .	100·00	..	13268
Scotch . .	Dalkeith . .	74·55	5·14	13102

[1] *Vide* "Third Report on Coals suited to the Steam Navy." By Sir H. De la Beche and Dr. Lyon Playfair. Folio. London, 1851.

The steaming value of fuels is usually taken for the atmospheric pressure of 14·7 lbs., or 1178°; but as locomotive boilers are worked up to 8½ atmospheres, or 1212° of total heat, the economic value must be estimated accordingly. Taking the initial heat of the water in the boiler as 52°, the theoretic value of the before-mentioned fuels contrasted with their practical value is as follows:—

STEAMING VALUE of 1 lb. of various Fuels.

Fuel.	Theoretical Pressures.		Practical Pressure.	Per Cent. of Theoretical Value.
	1 Atmosphere.	8½ Atmospheres.	1 Atmosphere.	
	lbs.	lbs.	lbs.	
Hydrogen . .	55·4	53·8	..	..
Aberaman Coal	13·0	12·6	10·7	82·56
Tanfield „	13·0	12·6	9·8	75·26
Ince-Hall „	12·9	12·6	9·4	72·95
Elgin . „	11·8	11·5	8·4	71·33
Coke, or Carbon	11·7	11·4	7·9	67·14
Dalkeith Coal .	11·6	11·3	7·1	61·20

This table shows, that with the utmost possible care, there is a practical difference in the value of different fuels, in the same boiler, to the extent of 21 per cent; and that the results follow the proportion of carbon generally, although the coke experiment, which was aided by a steam-jet blast in the chimney, clearly shows the beneficial influence of the hydrogen in the coals, for with 20 per cent. less carbon, the Elgin coals evaporated 4 per cent. more water than coke of the best description.

The coke experiment gives very nearly the same result, in this boiler, as is obtained from coke in the great majority of locomotive boilers; and as ordinary coke is not pure carbon, 5 per cent. may be fairly deducted from the carbon value, which leaves 10·8 lbs. of water, as the steaming value of coke.

A few practical results, obtained from very differently-proportioned boilers, are given below. They show a remarkable

coincidence of difference, with those obtained from different fuels in the same boiler.

Class of Boiler.	Area of Grate.	Total Heating Surface.	Ratio of Heating Surface to the Grate = 1.	Ratio of the Heating Surface to the Fire-box = 1.	Fuel consumed per Hour.	Fuel consumed per Foot of Grate per Hour.	Water by 1 lb. of Fuel.	Evaporation per Cent. of Fuel: Value per Cent.
	Sq. ft.	Sq. ft.			lbs.	lbs.	lbs.	
Haystack .	35	229	6·5	5·4	357	10·2	7·76	61·6
Waggon. .	21	342	16·3	7·6	217	10·3	7·87	62·4
,, . .	23	148	6·7	3·1	94	4·0	9·17	72·8
Cornish . .	23	961	41·7	26·2	82	3·5	10·53	81·0
LOCOMOTIVES.								
Loco. A . .	10	903	90·3	14·5	..	132·0	9·0	83·3
,, 234 .	14	1,215	87·0	13·4	757	53·0	8·12	75·2
Iron Duke .	21	1,769	84·0	12·4	1,727	82·0	8·32	76·8
Heron . .	10	707	70·7	13·2	829	82·9	7·74	71·6
,, . .	..	..	..	..	1,099	109·0	6·72	62·2
,, . .	..	..	..	..	708	70·8	7·66	70·9
Mr. McConnell's .	23	1,133	49·0	3·7	1,815	79·0	8·5	79·1
,,	..	..	..	..	1,041	45·0	8·27	76·5
,,	..	..	..	..	1,509	66·0	7·99	74·0

In this table, the standards of comparison adopted are, for the waggon and haystack boilers, 12·9 lbs. of water, being the value of Lancashire, or Ince-Hall coals; for the Cornish boilers, 13 lbs. of water, being the value of Welsh coals; and for the locomotive boilers, 10·8 lbs. of water, being the value of coke.

The difference in the value of fuels, in the trial boiler, varied about 21 per cent.; whilst the practical difference in various boilers, as seen in this table, is not quite 20 per cent. It is satisfactory to find that 9 lbs. of water, evaporated by 1 lb. of coke, in a locomotive boiler, exceeds the Cornish standard of comparative economy, by 2 per cent. of the value of the fuel used.

In daily practice, the locomotive boiler ranges from about 4 to 10 per cent. less than the Cornish boiler, and, apparently, without reference to the form, or proportions of any given type. Mr. McConnell's boiler, with a heating surface of only 3·7 times that of the fire-box, shows an equal evaporative economy to Engine No. 234, and to the "Heron," both having surfaces, 13 times that of the fire-box.

The following table, compiled from various authorities, gives the heating surface, the evaporative power, and the economy of a number of locomotive boilers, and three stationary boilers :—

RELATIVE HEATING SURFACE and EVAPORATIVE POWER of various LOCOMOTIVE and other BOILERS.

Boilers.	Ratio of Flues to Fire-box = 1.	Total Heat, say	Evaporation per hour. Total.	Per 1 sq. ft. of Heating Surface.	Per 1 lb. of Fuel.	Velocity per Hour.	Net Load.	Working of Engine.
		Sq. ft.	Cub. ft.	Cub. ft.	lbs.	Miles.	Tons.	
Haystack . . .	5·46	229·5	45·0	·196	7·76	..	..	Ord.
Waggon . . .	7·6	342·8	34·4	·100	7·87	..	..	,,
Cornish	26·21	961·6	41·4	·043	10·53	..	..	,,
Killingworth . .	4·50	124·0	47·8	·391	4·25	9	..	,,
Rocket	5·89	137·8	18·2	·132	5·30	14	..	Max.
Sanspareil . . .	4·75	90·3	24·0	·265	2·16	14	..	,,
Novelty, 2nd . .	7·48	280·0	40·0	·142	10·4	..	..	Exp.
Lincoln and Manchester . . .	7·01	334·5	55·4	·165	6·2	21	..	Ord.
Patentee . . .	8·64	482·0	76·8	·159	7·8	..	..	Exp.
Harvey Combe. .	6·69	390·1	106·0	·271	7·8	30	..	Max.
Bury, No. 15 . .	9·68	417·4	94·0	·225	7·4	30	..	,,
North Star . . .	9·35	724·7	201·6	·277	7·57	33	40	,,
Premier. . . .	6·25	377·0	154·0	·408	7·4	26	..	,,
Cyclops. . . .	6·20	699·0	120·0	·177	7·69	30	60	Ord.
Hesperus . . .	9·17	803·5	116·0	·158	10·3	28	60	,,
Royal Star . . .	8·95	821·5	134·0	·163	7·6	30	60	,,
No. A	14·5	903·0	170·0	·188	9·0	48	60	Max.
Ixion	6·2	700·0	210·0	·300	7·4	55	60	,,
Iron Duke . . .	12·6	1769·0	230·0	·130	8·32	50	70	Ord.
Courier. . . .	11·6	1740·0	203·0	·116	7·19	50	70	,,
Sphynx	9·97	951·7	233·0	·244	8·75	12	..	Exp.
Caledonian . . .	13·94	704·6	83·2	·118	8·43	35	..	,,
Edinburgh and Glasgow . . .	10·47	718·6	91·0	·126	8·5	25	..	,,
London and South-Western . . .	10·97	898·5	152·0	·169	8·9	50	..	,,
London and North-Western, 234 .	12·43	1125·4	78·0	·069	7·94	32	70	,,
,, Heron .	13·26	707·0	110·0	·155	7·76	38	85	,,
,, Mr. McConnell's .	3·84	1133·0	191·0	·168	7·79	36	170	,,
,, ,,	..	..	137·0	·120	8·29	38	85	,,

In Mr. McConnell's engines, the fire-box is carried about 5 feet into the cylindrical part of the boiler; and that extension may be an arch, or other convenient form, as the particular class of engine requires. The tubes are 303 in number, each 7 feet long by $1\frac{3}{4}$ inch in diameter; but it is calculated that by using

$1\frac{3}{8}$-inch tubes, the surface would be increased 30 per cent. without detriment to the engine. Its heating surface is—

—	Outside.	Inside.	With $1\frac{3}{8}$ in. Tube outside.
	Sq. feet.	Sq. feet.	Sq. feet.
Fire-box . .	260	260	260
Tubes . .	978	873	1,270
Total .	1,238	1,133	1,530

As regards rapidity of evaporation per square foot of the total heating surface, it will be seen, by the table, that it follows closely the ratio of the fire-box area, being greatest in the small boilers, and least in the largest boilers. This is probably due to the tubes being too close together in the latter class. The proper disposition of the tubes, to aid the ascent of the steam, early attracted and still requires notice.

The ordinary practice is to place the tubes alternately, hence the steam generated by the lowest, has to run round each alternate tube to the surface. In boilers having sixteen, or more rows of tubes, thus placed, it is quite possible, that the loss of time, in the ascent of the steam, may occasion a relatively slower evaporation; and that by placing the tubes in vertical rows, this might be remedied. With small tubes, the sacrifice of heating surface might be inconsiderable, since 30 per cent., more heating surface, could be got, in the same space, by using tubes $1\frac{3}{8}$-inch diameter instead of $1\frac{3}{4}$-inch diameter.

Mr. Stephenson's early practice was, to use tubes $1\frac{5}{8}$-inch in diameter, and the 'North Star,' with tubes only $8\frac{1}{2}$ feet long, when tried to its utmost power, and speed, by Dr. Lardner, in 1838, evaporated $7\frac{1}{2}$ lbs of water by 1 lb. of coke. This shows how little advance has been made in boiler economy, as distinct from the economy of using the steam after it is generated. In the 'North Star' there was no 'lap' on the slide valves, and the blast pipe was several inches up the chimney, so that its performance was limited by the back pressure of the escaping steam. The 'lap,' and a shorter blast pipe, were subsequently added by Mr. Andrews.

In ordinary working, the greatest portion of the heat passes

through the lowest tubes of large boilers; whilst in small boilers, it necessarily passes through tubes nearer the surface of the water, so that the want of a free and large evaporating surface of water, appears to be the greatest defect in large locomotive boilers. For, if the steam has not only to struggle up the winding tubular pathway, but has also to force its way from the widest part of the boiler, to a surface 20, or 30 per cent. less, as is the case in many of the large boilers, their relative slowness of evaporation may be accounted for, by the difficulty with which the steam reaches the surface, both from the side and lower tubes. In this respect, Mr. McConnell's boiler has a decided advantage, from its long unbroken surface, near the top of the water. In all the boilers made for Watt, great attention was paid to keep the evaporating surface rather below the widest part of the boiler, as essential to rapidity of steaming, and economy of fuel.

When a locomotive boiler of 58 inches diameter, has only 10 per cent. of steam space, to 39 per cent. of water space, and 51 per cent. of heating space, it is seen how limited must be the evaporating surface, compared to a Watt boiler, where the steam and water spaces were equal.

Compared with a large boiler, as at present constructed, the small boiler has the following advantages—a shorter ascent for the steam,—the heat passes through the tubes nearer the surface of the water, and there is a much larger ratio of evaporating surface, as compared with the water surface. All these points tend to evaporative rapidity.

It is a question open to discussion whether, on a fair trial, a boiler with its tubes in vertical rows, with free vertical steam channels between them, and an evaporating surface nearly equal to the diameter of the boiler, would not give as good results, as the same boiler fitted with a greater number of alternate tubes, and the water surface about 18 inches above the centre of the boiler.

The tabular summary of the trials of boilers, from the 'Rocket' to the present time, shows that, with the ordinary locomotive boiler, evaporative economy follows the increase of the tubular surface, but that evaporative rapidity follows the ratio of the increase of the fire-box surface. Now since the power of a locomotive depends upon the rapid generation of

steam, and the economy of fuel depends upon the velocity of running, it is evident that economy of fuel may be obtained at too great expense of speed and power.

The gauge trials showed this clearly, for with 200 square feet less heating surface, the 'Ixion' evaporated 40 cubic feet of water per hour more than the 'A' engine, or 24 per cent. difference. The economy of fuel was about 15 per cent. in favour of the 'A' engine; but it was obtained under circumstances protested against at the time, and it will scarcely be doubted but that the extra performance of the 'Ixion' was more than equivalent to the economy of the engine 'A,' since power and speed were the prizes contended for, and not economy of fuel alone.

In practice, rapidity of evaporation is as essential as economy of fuel. The boilers with long tubes are the most economical of their class, and the temperature in the smoke-box, at their running velocity, shows that they are not too long, so far as the fuel is concerned; therefore, if it requires a tube 14 feet long, for a speed of thirty miles an hour, it would require a much longer tube, for a velocity of sixty miles per hour, to maintain an equal economy of fuel, or temperature, in the smoke-box. At a speed of thirty miles, the heat may be fairly transmitted to the water, but it may cease to be so transmitted at forty miles, and become wasteful at fifty miles, or sixty miles per hour, as is daily experienced.

In the tabular comparison of boilers, in Mr. Clark's Paper, the Great Western speed is given as fifty miles, the Caledonian as from thirty miles to forty miles, and the Edinburgh and Glasgow—as under twenty-nine miles. With such discrepancies of speeds, there can be no real comparison; for if the economical small engines can neither maintain the speed, nor exert the power of large engines, then all comparison ceases. Economy of fuel also varies with the load and speed, so that comparing heavy engines, at high speeds, with light engines, at low speeds, is much the same as comparing goods' and passenger engines, without reference to the duties they were designed to perform.

Large boilers, mounted on high wheels, have the advantages of a slower rate of combustion, and of longer time to transmit the heat to the water, than boilers on low wheels; and at equal

velocities these recognised elements of economy should give the greatest evaporation.

The number of draughts of steam from the boiler per hour, depends upon the height of the driving-wheels, and, all other circumstances being alike, there will be the least amount of priming, with boilers on high wheels.

For different sized driving-wheels, and different velocities, the draughts of steam, and the time allowed for the absorption of the heat, in locomotive boilers, are comparatively as follows :—

Diameter of Driving Wheels.	Draught of Steam and Blasts per Second for a speed per hour of			Ratio of Draught and Time to 8-feet Wheel.	Difference in Favour of 8-feet Wheel.
	40 Miles.	50 Miles.	60 Miles.		
Feet.	No.	No.	No.	Per Cent.	Per Cent.
5½	13·58	17·0	20·4	68·6	31·4
6	12·4	15·5	18·7	74·8	25·2
6½	11·5	14·3	17·4	80·4	19·6
7	10·7	13·3	16·0	87·5	12·5
7½	9·95	12·4	14·9	93·8	6·2
8	9·1	11·6	14·0	100·.	..

This table shows, that the boiler on 8-feet wheels, has an advantage of 19 per cent. over the 6½-feet wheels, 25 per cent. over the 6-feet wheels, and 31 per cent. over the 5½-feet wheels, in the time given for the absorption of heat, and the escape of steam.

The wear of the tubes also decreases, with the decreasing number of blasts through them. This has been found to be the case with the Great Western locomotives. On that line a set of tubes has run with

5-feet wheels	from	62,018 to	68,728	miles.
6 „	„	71,264 to	83,425	„
7 „	„	74,778 to	94,620	„
8 „	„	116,634 to	140,000	„

The locomotive boiler may be said to have originated, in this country, in 1829, with the 'Rocket,' although it was not the tubes, but the blast-pipe, which decided the issue at that memorable trial; for without the blast-pipe, the 'Rocket' only

realised about 10 miles per hour, whilst with it the speed attained was about 30 miles per hour.

With nearly 60 per cent. less heating surface, and 13 per cent. greater load, the 'Sanspareil' evaporated 24 cubic feet of water per hour, whilst the 'Rocket' only evaporated 18¼ cubic feet. Taking their relative surfaces, this gives, in round numbers, double the evaporative rapidity per square foot for the 'Sanspareil,' and rather more than double the economy of fuel for the 'Rocket.'

The table also shows, that, without reference to speed, there are only four boilers which exceed the Great Western, or Mr. McConnell's boilers, in evaporative economy. After conducting a series of eighteen experiments with Mr. McConnell's engine, Mr. Marshall reports, "The amount of this combustible gas appears to be important, as the combustion-chamber in the new engine is maintained full of flame, reaching to the mouth of the tubes." He also states, that the pressure of steam increases rapidly, when standing at the stations; that on one occasion it rose 35 lbs. in 3½ minutes; on another 18 lbs. in 3 minutes, but that the damper prevented any particular waste of steam. These eighteen experiments were extended over a distance of 1,398¾ miles. The steam was up 4,860 minutes, and deducting the time lost in ninety-six stoppages = 2,279 minutes, the rate of travelling was 32½ miles per hour, over the rails in a bad state, during the months of December 1852 and January 1853.

Whilst running, the consumption of coke was 52,637 lbs. and the water used was 418,932 lbs.; giving an evaporation of 7·97 lbs. of water by 1 lb. of coke. As experience was gained in managing the fire, the evaporative economy increased up to 9 lbs. of water by 1 lb. of coke. During the last five trials, the mean speed was 35 miles an hour, with 70 tons; there were twenty-nine stoppages in 413¾ miles, and an evaporation of 8½ lbs. of water by 1 lb. of coke.

The following table gives the results of some comparative trials, with two ordinary engines, called the 'Heron' and the 'Prince of Wales,' one of Mr. McConnell's engines, (No. 291,) and one of Mr. Stephenson's eight-wheeled engines, (No. 234). The 'Heron' and 'Prince of Wales' had cylinders 15 inches diameter, and stroke of 20 inches, with driving-wheels 6 feet

diameter. Mr. McConnell's engine had cylinders 18 inches diameter, and stroke of 24 inches, with driving-wheels 8 feet diameter; whilst Mr. Stephenson's engine had cylinders 16 inches diameter, and stroke of 24 inches, with driving-wheels 7 feet 1 inch, diameter.

ENGINES.	Net Load.	Coke. Total.	Coke. Per Mile.	Water Evaporated by 1 lb. of Coke.	Distance run.	Velocity in Miles per Hour.	Direction of running.	Date.
		lbs.	lbs.	lbs.	Miles.			1853.
McConnell's (291)	45	2,470	22·25	5·92	111	42·1	Up	Feb. 24
Heron . . .	45	2,192	19·75	7·17	111	42·1	,,	,,
McConnell's (291)	65	3,310	29·82	6·4	111	36·5	Down	25
Heron . . .	65	3,479	31·34	7·32	111	34·5	,,	,,
McConnell's (291)	85	3,040	27·38	6·59	111	34·2	Up	26
Heron . . .	85	2,872	25·88	7·74	111	32·0	,,	,,
McConnell's (291)	105	3,420	30·81	6·84	111	31·0	Down	27
Heron . . .	105	3,374	30·41	7·44	111	30·0	,,	,,
McConnell's (291)	125	3,347	30·15	8·14	111	25·0	Up	Mar. 1
Heron . . .	125	3,144	28·32	7·66	111	25·0	,,	,,
McConnell's (291)	85	3,220	29·0	7·03	111	35·8	Down	4
Heron . . .	85	3,179	28·64	7·56	111	33·6	,,	,,
McConnell's (291)	85	3,157	28·44	8·27	111	38·0	Up	7
Heron . . .	85	3,210	28·91	6·72	111	38·0	,,	,,
McConnell's (291)	85	2,942	26·45	8·3	111	38·0	Down	5
Heron . . .	85	2,815	25·37	7·97	111	36·9	,,	,,
McConnell's (291)	170	4,529	40·8	7·99	111	36·4	Up	8
Heron and Prince of Wales	170	4,851	43·70	8·38	111	34·5	,,	,,
Stephenson's (234)	35	1,853	22·39	7·19	82¾	27·0	Up	Mar. 10
,,	60	1,973	23·84	8·09	82¾	31·5	Down	,,
,,	50	1,899	22·94	7·94	82¾	25·7	Up	11
,,	60	1,996	24·12	7·67	82¾	. .	Down	,,
,,	60	1,920	23·20	8·0	82¾	26·0	Up	12
,,	70	1,959	23·67	8·12	82¾	32·0	Down	,,

With few exceptions, the speed was in favour of Mr. McConnell's engine; and as time is equivalent to coke, at equal speeds, the consumption of coke would have been less per mile. For instance, with the load of 170 tons Mr. McConnell's engine performed the distance in ten minutes less time than the 'Heron' and the 'Prince of Wales,' which is equivalent to 6 miles running. The coke consumed was 4,529 lbs. and taking the distance as 117 miles, it gives 38·7 lbs., and one set of men, against a consumption of 43·7 lbs. of the two engines, and two sets of men. In like manner, in some of the other trials, the time was 13 minutes in favour of the new engine.

If the consumption of coke is given correctly for the two engines, it would appear, that two engines with a load of 170

tons consume about 15 per cent. less coke, than they would do separately, each with 85 tons.

As, however, the ratio of evaporation gives about 2 tons more water used by the two engines for the lesser duty, than was required by Mr. McConnell's engine for the greater duty, it indicates, that either the extra machinery of the second engine required this power, or that priming took place, through the number of draughts from the boiler, in several of the trials.

It is stated, that speeds of nearly 60 miles an hour with the heavy load, and about 70 miles an hour with the light loads, have been attained with Mr. McConnell's engine; whilst the trials of the engines with driving-wheels 8 feet in diameter on the Great Western, which have frequently run 53 miles in 50 minutes, and even in 48 minutes, with express trains, sufficiently demonstrate that a maximum speed, of 70 miles an hour, is attainable by such engines.

Since it is a matter of experience, that no new engine, or boiler, works so well as an older one, which has reduced the substance of its tubes, and polished its own bearings, and that each locomotive has its own constitutional peculiarities, the first performance of the first engine of a class, may, or may not, be the best as regards its power and economy. Taking the experiments as the first performance of a new engine, they are decidedly favourable. The evaporative economy ranges from about 7·6 lbs. to 8·5 lbs. of water per 1 lb. of coke, under ordinary circumstances, and up to 9 lbs. under favourable ones, or the assigned limit of the best boilers with long tubes. These evaporative results are the best proof, that the heat is fairly transmitted to the water, by the new form of boiler.

Mr. McConnell's present boiler may, or may not, be judiciously proportioned in all its parts, but that is not the question, since if it accomplishes this rate of evaporation, it would appear to be proved, that there are other and more convenient forms of boilers, adapted for locomotives, than those in general use.

Locomotives require to be constructed of different power for different duties. Mr. McConnell's boiler seems to admit of considerable variety of form and size, and of inside cylinders, with a low centre of gravity and high driving-wheels, so long felt to be a desideratum on the narrow gauge; although it is held by some engineers, that outside cylinders are not ob-

jectionable, more particularly on Mr. Crampton's plan, with the driving-wheels behind the fire-box.

By arching the combustion-chamber of Mr. McConnell's boiler to any extent desirable, the height of the boiler may be reduced at pleasure, and yet the cylinders may either be close together, or not, as might be preferred for the valve-gear arrangements.

As at present constructed, the position of the cylinders of the three varieties of engines, already referred to, with wheels of 8 feet in diameter, are,

Mr. McConnell's Engine	27	inches between their centres, or	100 per cent.
'Iron Duke' . .	50	,, ,, ,,	185 ,,
'Liverpool' . . .	76	,, ,, ,,	281 ,,

This shows a difference of 85 per cent. over the 'Iron Duke,' and 181 per cent. over the 'Liverpool,' in favour of the central traction of the pistons of Mr. McConnell's engine.

Thus fairly tested by the highest standard, Mr. McConnell's engine takes a high position, alike for its power, economy, and constructive facilities.

In comparing different boilers, or engines, it is necessary to keep in view the pressure of the steam, under which the evaporation takes place. For although a cubic foot of water, as steam of equal temperature, will perform an equal duty in any engine as a whole; yet it gives out an increasing power as the temperature is increased under which it is generated. This difference is shown in the following table.

It may be remarked, that as a more convenient dynamic standard than the ordinary one, has often been suggested, the natural law that a cubic foot of water, as steam of the pressure of the atmosphere, gives out exactly 60,000 lbs. raised one foot in one hour, it readily suggests itself as a convenient unit for two horses' power, and is also in accordance with Watt's practice, of estimating the power of his engines, by a cubic foot evaporated per horse-power per hour. It has also the advantage of being exactly $\frac{10}{11}$ths of the usual 33,000 lbs. value, so that they are easily convertible into each other. The inconvenience of changing standards is however fully appreciated, but for convenience the 30,000 lbs. value is taken as the horse-power.

Power of a Cubic Foot of Water, as Steam of different Temperatures.

Temperature.	Pressure per square Inch.	Total Power.	Atmospheric Resistance.	Available Power in 30,000 lbs. H.P.
Fah.	lbs.	lbs.	lbs.	
212	14·7	60,000	60,000	..
295	60·0	67,680	17,254	1·671
306	70·0	68,544	14,400	1·804
315	80·0	69,504	12,776	1·89
324	90·0	70,200	11,470	1·958
332	100·0	70,800	10,411	2·013
339	110·0	71,544	9,563	2·066
345	120·0	72,000	8,823	2·106
352	130·0	72,696	8,223	2·149
357	140·0	73,250	7,694	2·185
363	150·0	73,600	7,235	2·212
368	160·0	73,728	6,776	2·231
378	180·0	74,736	6,106	2·288
387	200·0	75,569	5,541	2·334

In this table, the atmospheric resistance is taken, for the volume due to the pressure, without reference to the expansive action of the steam. For, if that volume is expanded fourfold, the atmospheric resistance has also to be overcome four times; therefore the economical working of steam, expansively, is limited by the aggregate of the atmospheric resistance, and the friction of the mechanism. It will also be noticed, how rapidly the power derivable from a cubic foot of water, as steam, increases with the pressure, irrespective of expansion; and that from being equal to the atmosphere at 14·7 lbs. pressure, it is about fourteen times greater than the atmosphere at 200 lbs. pressure per square inch, or as steam of 75,569 lbs. power, to the atmospheric resistance of 5,541 lbs.

The investigation, by Mr. D. K. Clark, of numerous boilers in daily use, concludes by recommending a proportion of 85 square feet of heating surface to each square foot of fire-grate, as consistent with consuming 112 lbs. of coke per square foot of grate, and an evaporative power of 9 lbs. of water by 1 lb. of coke.

As the formula takes no cognizance of the two important elements of load and speed, its application must be limited to one particular class of engines, under given conditions; but it is not adapted to the fluctuating conditions of ordinary traffic. If the proposed formula can be amended, to embrace this fluctuating condition of railway traffic, it will be a useful effort to apply defined rules, for each class of engines.

The various tables given in this Paper show clearly, that the proportion of tubular and fire-box surface, may be varied for constructive, or other requirements, without any appreciable loss; and that the Great Western, Crampton's, and McConnell's boilers, on 8-feet wheels, combine the acknowledged elements of evaporative economy.

By way of contrast, with the latest designed locomotive,—that by Mr. McConnell,—allusion may be made to the first locomotive constructed at Paris, from the designs of M. Cugnot, in 1769-70, or eighty-three years previously. Cugnot's boiler was of a flattened spheroidal form, with two separate fire-places inclosed in an outer case. The mechanism and boiler were mounted on a bogie frame, with a single leading wheel in front, 50 inches in diameter, having a tire 7 inches broad, with a fluted surface to bite the road. It had two vertical single-acting cylinders, each 13 inches in diameter, arranged on Papin's plan—usually known as Leupold's—with a four-way cock, which admitted steam alternately from the boiler to one cylinder, and from the other cylinder to the atmosphere. The piston rods worked downwards, as afterwards adopted by Bull, in Cornwall, to avoid Watt's patent, and now common in pendulous and other engines. Locomotion was obtained by the piston rods working a double-ended ratchet-wheel catch on each side of the driving-wheel, and their alternate action maintained rotation. The motion was reversed by changing the acting end of the catch, and was stopped by throwing both ends out of gear.

It may be remarked, that it is a question open to discussion, whether, as traction is preferable to propulsion, it would not be preferable to place the driving-wheels of all locomotives in front, like Cugnot's, than as they are usually placed.

The safe strength of boilers is another and most important part of locomotive economy. As at present constructed, a locomotive boiler is far from being a homogeneous structure, and as it becomes old, the parts which have to sustain the alternating force of expansion and contraction, lose their original cohesive force, and an explosion occurs. If the structure were homogeneous, and of equal elasticity, or nearly so, it would tend to greater safety in all boilers; and since Mr. McConnell's boiler shows, that the ordinary form may be departed from, as regards the tubes, it suggests that the rectangular fire-box might

be changed into the stronger cylindrical form, and thus the real strength of the boiler would be increased.

Experience leads to the opinion, that the safety-valves and the steam-pipe orifices are the two most dangerous parts of any boiler; and that explosions are much more likely to occur at these parts, or directly opposite to them, than at any other part.

This opinion is based upon the fact, that several locomotive boilers have burst at those parts, arising, it is believed, from the concentrated rush of steam to the steam-pipe, or to the safety-valve, as either might be opened, and to the internal equilibrium in a weak boiler, becoming thus destroyed.

This would produce a local pressure, for an instant, far greater than the ordinary pressure, and if the point of collision, or its opposite point of reaction, failed to resist that pressure, rupture would ensue, even though the safety-valve should be in perfect order, and should not be overloaded. The vast elastic force, of the expanding water and steam, thus suddenly released, would, like any other spring, exert a force far beyond the limit due to the quiescent pressure, and after investigation might show, that the explosions had frequently resulted from tampering with the safety-valves. It may also be noticed, that the ordinary safety-valve does not open its entire area to any boiler, but only a concentric ring of about one-eighth, or one-fourth of an inch wide, which is too little for such expansive force, even when directed against the valve itself. Suppose, for example, that the pressure in a boiler is 100 lbs. per square inch, in a quiescent state, but that the sudden opening of the regulator, or safety-valve destroys that equilibrium; there is then an instantaneous rush of steam towards that opening, and a simultaneous formation of steam by the disturbed water; therefore, it is not the 100 lbs. pressure which the boiler has to sustain, but it is the collision of various forces of 100 lbs. each, sustained by the rapid formation of more steam, which the boiler has to resist, and which leaves their destructive energies only too apparent, when rupture ensues.

This view of the explosive force of steam and heated water, does not involve any supposed tampering with, or neglect of valves, so often mooted, and it is believed to be more in accordance with the known powers of elastic force and boiler resistance.

Before closing these remarks, it is desirable also to call atten-

tion to the numerous cases of passenger-engines, or trains running off the rails, without apparent cause, although goods', or slow trains seldom meet with the same casualty.

This points directly to velocity as the ruling cause, and to deeper wheel-flanges as a simple and good remedy. It is quite probable, that many of these accidents might have been prevented, by a flange only one-half inch deeper than the present one; for, at the high velocities now run, a flange of one inch deep, is but a narrow limit between safety and danger. An extension to 1½ inch, or even 2 inches, where the rails would admit of it, would greatly increase the safety, without, in the slightest degree, increasing the friction in running.

When the late Mr. Stephenson designed the Liverpool and Manchester Railway, and speeds of only fifteen miles, or twenty miles an hour were contemplated, flanges about one inch deep were sufficient, as is still proved by goods' and other slow trains. But now that heavy engines and high speeds of fifty miles and sixty miles an hour, over indifferent roads, are in the ascendant, a greater depth of flange is required, alike for public safety and railway economy.

From what has been stated, it may be concluded—

That different boilers at different speeds, or the same boiler at different velocities, are not economically comparable.

That fuels differ nearly as much in their steaming powers as boilers.

That a cubic foot of water, as steam, gives out a power varying with the temperature of that steam.

That boilers, with pressures varying from 90, 100, 110, to 150 lbs. per square-inch, are not tractively comparable.

That evaporative economy is not confined to any one form of boiler, and is influenced by the fuel used.

That economy of evaporation may be purchased at the cost of speed and power.

That the economic length of tubes, in ordinary boilers, depends upon the velocity of running and the temperature of the steam.

That Mr. McConnell's boiler gives great constructive facilities, for further improvements in locomotive boilers.

That the Great Western, and other boilers on high wheels, combine the elements of evaporating power and economy.

That boiler explosions are frequently due to internal commotion acting against some local point.

That deeper wheel-flanges would increase the public safety.

The discussion upon the Paper, No. 887, "Experimental Investigation of the Principles of the Boilers of Locomotive Engines," by Mr. D. K. Clark, being resumed, was continued throughout the evening.

April 12, 1853.

JAMES MEADOWS RENDEL, President, in the Chair.

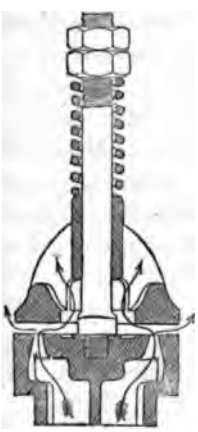
No. 888.—"On the Concussion of Pump Valves." By WILLIAM GEORGE ARMSTRONG, M. Inst. C. E.

IN constructing force pumps, for working hydraulic cranes, and other machines of a similar nature, under a high pressure, considerable difficulty has been encountered, in arriving at a form of valve free from injurious beat, or concussion; and as, after many experiments, the object appears to be attained, it may not be uninstructive to describe the proceedings.

The head of water, against which the pumps were required to act, in the particular instance alluded to, was equivalent to a column of 1,200 feet, and was obtained, artificially, by means of an accumulator, or loaded press, which served, in every respect, as a substitute for a reservoir of that elevation. These force pumps were fixed at each end of the cylinder, and the plungers worked in a direct line with the piston of a high-pressure engine, with a horizontal cylinder and regulating fly wheel.

In designing the pump valves, the Author proceeded upon the generally received opinion, which is, that concussion is caused by the fall of the valve upon its seat, and with that view, in order to afford the necessary passage for the water, with an extremely small rise, the valves were made of an annular form, to allow the water to escape on all sides; and very large, in proportion to the size of the plunger.

Fig. 1.

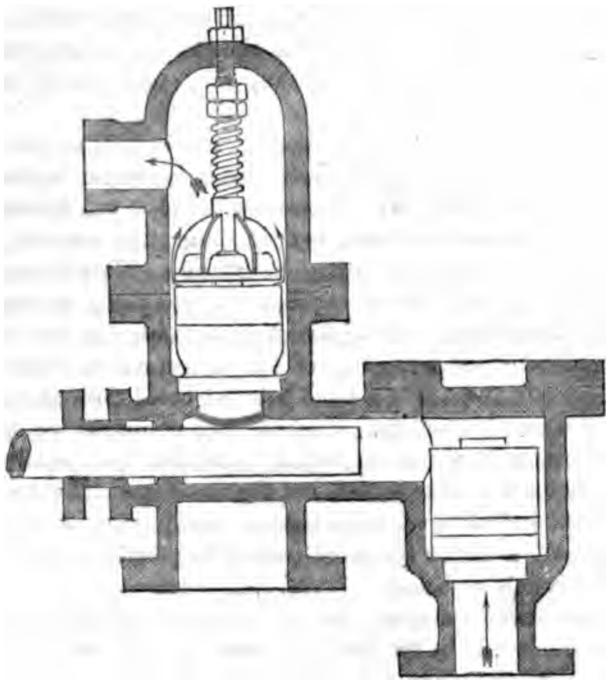


A spiral spring was also applied, to press upon each valve, to insure its closing promptly, at the termination of each stroke; and a screw adjustment was used, to vary the pressure of the spring.

The form and construction of this valve are exhibited by Fig. 1, and the general

form of the pump by Fig. 2, the latter being slightly varied from the reality, for the sake of clearer illustration.

Fig. 2.



In order that the water might flow into the pumps independently of suction, the cistern for feeding them was placed at a considerable elevation. It was calculated, that, with the pressure given by the spring, the greatest rise of the valve would not exceed one-twentieth of an inch, and as this rise would gradually diminish, as the plunger travelled from the middle towards the end of the stroke, it seemed difficult to conceive, that any concussive effect could attend the final closing of the valve.

Upon trying the pumps, however, when fitted with these valves, a violent shock was found to take place, once during each stroke of the plunger; and as this shock was identical, in point of time, with the fall of the suction valve, it was assumed, that the defect was in that valve, and not in the delivery valve. When

the engine worked rapidly, the violence of the shock was increased, and on one occasion the pump barrel, although disproportionately thick, for the pressure it was intended to bear, burst (apparently) from the blow. An increase of pressure on the accumulator, was also found to augment the violence of the beat, although it appeared obvious, that the pressure existing above the delivery valve, could not in any way affect the fall of the suction valve.

The pressure of the closing spring was varied, so as alternately to increase and diminish the rise of the suction valve, but no change was produced; occasionally, the blow was diminished without any apparent cause, but whenever this occurred, the pump was observed to be acting inefficiently. Notwithstanding the violence which attended the action of the pump, no appearance of hammering could be detected, on examining the valves.

In order to insure the fall of the suction valve, before the termination of the stroke, a small hole was bored through it, and covered with a leather flap, which having no weight, or spring pressing upon it, would be certain to remain open, until after the valve itself became seated, but the result was still the same.

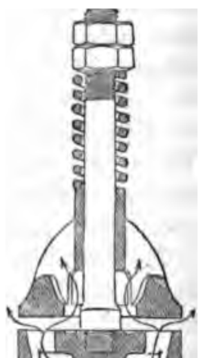
The suction valve was next fastened firmly down on its seat, leaving only in action the small leather flap, but the shock continued precisely as before.

It then became evident, that the noise and concussion could not be produced, by the fall of a small piece of leather upon the metal of the valve, and it appeared that the cause would probably be found in the delivery valve, the rise of which took place at the instant of the concussion. This was soon ascertained to be the fact, and it only remained to account for the effect.

It will be observed, by reference to Fig. 1, representing the delivery valve, that while the entire area of the valve is acted upon by the downward, or closing pressure, only that portion of the under surface which covers the annular opening, is acted upon by the upward, or lifting pressure. It is obvious, therefore, that since the area, acted upon from below, is very much less than that acted upon from above, a momentary excess of pressure must be produced, by the plunger in the pump barrel, in order to raise the valve from the seat. The material of the pump barrel will thus, for an instant, be unduly distended, and a sudden collapse will take place, immediately on the starting of the

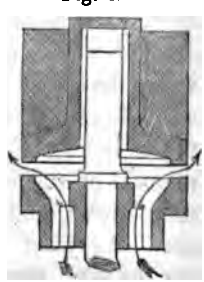
valve. In the case of the valve, shown in Fig. 1, the surface acted upon below is only one-sixth of that above, so that the pressure per square inch, exerted by the plunger in starting the valve, would be six times that of the column to be lifted; excepting so far as this difference might be diminished, by the imperfect fitting of the surfaces; and here it may be observed, that the concussion was invariably most sensible, when these surfaces were very accurately fitted. All the effects observed agreed with this explanation; the bursting of the pump barrel; the increase of the shock, by the increase of the pressure; and the absence of any appearance of hammering on the valve faces, were now clearly intelligible. It also became evident, why a diminution of noise took place, when the pump acted imperfectly, because the interposition of any grit, or other substance, between the valve and its seat, while it impaired the efficiency of the pump by the leakage it occasioned, would render the contact imperfect, and enable the lifting pressure to act upon an increased area.

Fig. 3.



In conformity with this view of the subject, the annular opening was extended, as shown in Fig. 3, so as to diminish the bearing surfaces, and lessen the difference between the areas above and below, and by this means the shock was greatly diminished. It was then perceived, that since the bearing surface in the annular form of valve must necessarily be large, in relation to the area of the water passage, a valve of this description, used as a delivery valve, would be more subject to concussion than one of a more ordinary construction.

Fig. 4.



The annular valve was therefore abandoned, in favour of the single beat valve, shown in Fig. 4. In this valve, the bearing surfaces were reduced, as much as possible, so as to render the difference of areas inconsiderable, and the result was, that a smooth and nearly noiseless action was obtained, even when the pump made one hundred strokes per minute.

In the course of experiments made in connexion with this subject, valves of different forms, faced with leather, or with gutta percha, were also tried; but these were equally subject to concussion, whenever the difference of the area of the upper and the under surfaces was considerable.

It appears, therefore, that in all cases in which pumps are to be worked rapidly, against a heavy pressure, it is important, that the valve used for the delivery should be so constructed, as to yield with facility to the pressure of the plunger, or piston, and to attain this object, the area of the valve, acted upon from beneath, must bear a large proportion to the area pressed upon above. But although, in the instances described, the cause of the beat was distinctly traced to the rise of one of the pump valves, it is not to be inferred that such is always the case. Generally speaking, the concussion undoubtedly arises from the fall of the valve, and the violence of the beat is attributable to the valve remaining open, until after the turn of the stroke, and being then suddenly forced down, by the weight of the returning column. The causes of the valve remaining open, beyond the time at which it ought to close are—1st. An excessive rise in the valve, which requires too much time for its closing; and 2nd. The overrunning of the column in the rising, or delivery pipe, consequent upon the momentum imparted to it by the previous stroke of the pump.

The first of these causes is universally admitted, and is met by the practice of making the valves of large dimensions, and frequently with two, or more fitting surfaces, so as to afford a large passage for the water, with a small rise of the valve; but the second cause, though less generally regarded, deserves careful attention.

If a common force pump, with a long delivery pipe, be worked quickly, by hand, or otherwise, and a pause be made, after each descent of the plunger, it will be found, that the quantity of water thrown at each stroke, will very considerably exceed that which is displaced by the plunger; and if the fingers be applied to the mouth of the suction pipe, so as partially to close it, a renewal of sucking will be perceived after the termination of each stroke, and before the commencement of the succeeding one. Again, if a small opening be made in the delivery pipe, near to the pump, it will be found, that water will issue,

during the forcing stroke, but that air will be drawn in immediately afterwards.

These effects are rendered more decided, by increasing the length of the delivery pipe, and by contracting its diameter; and they are obviously produced by the continued movement, or by the overshooting of the column due to its momentum.

Now a very moderate velocity, in a delivery pipe, will be sufficient to produce this effect, in some degree, and wherever it takes place, unless an efficient air vessel be used, the valves must necessarily remain open, beyond the time at which they ought to close, and the result will be a concussion, the force of which will depend on the height and length of the column, as well as on the speed of the pump, and the frequency of the stroke.

These considerations show the importance, not only of adopting the usual expedients, for limiting the rise of a pump valve, but also of preventing the overshooting of the column, either by making the delivery pipe sufficiently large, or by applying means of keeping up a continuous motion of the column, without drawing tail water through the valves.

It is hoped, that the foregoing observations, may throw light upon some points connected with the general subject of the concussion of pump valves, and that by so doing, they may tend to the removal of an evil, which, at present, imposes a limit to the speed at which pumps can in most cases be worked, and thereby involves the necessity of larger machinery than would otherwise be requisite.

The Paper is illustrated by four drawings, Nos. 4582-3-4 and 5, from which the woodcuts figs. 1 to 4 have been compiled.

Mr. E. A. COWPER exhibited two diagrams of new arrangements of the ring-valve, in which the rings were arranged in the form of an amphitheatre, the outside, or larger rings being placed higher than the inside, or smaller rings, so as to give great convenience for obtaining a long steady guide in the centre. This form was being adopted in several 40 H.P. engines.

Mr. HAWKSLEY thought the description of the action of the valves given in the Paper was very true and clear. Concussions were frequently caused by the return of the piston, through a space, upon a body of quiescent water, without any action of the valves. It did not follow, that because the blow might occur at the moment of the opening of the delivery valve, it was caused by the motion of the valve.

Mr. SCOTT RUSSELL thought that, the conical form of the apertures, for the passage of the water, might have some influence in producing the shock, by directing the flow upwards, and imparting great velocity to the column.

Mr. ARMSTRONG had used the annular valves, because the beat was large, and there was ample escape for the water; and the shock was proportionate to the difference of the upper and lower areas. The opening was continuous all round, and was much larger than the area of the inlet pipe. He could not, therefore, admit that the shocks were at all due to this form. In proof of the violent effects caused by the overshooting of a column of water, he might mention, that if water was rapidly discharged, and the column was allowed to rush violently forward, a vacuum appeared to be formed behind, and frequently pipes had been burst by the reflux, without any considerable pressure of head.

Mr. HENRY MAUDSLAY said, that in applying vulcanized India-rubber for valves, if the substance was fixed, it cut itself rapidly away, by falling into the same grooves; but if the discs of India-rubber were allowed to move about, it wore excellently. In corroboration of this opinion, he produced an old air-pump bucket-valve, made of India-rubber, which had been at work for some time, in one of the engines at Messrs. Maudslay and Field's manufactory, Lambeth.

Mr. D. THOMSON had tried vulcanized India-rubber valves to avoid concussion, under heavy pressure, but he had not found

them to diminish the shock of the beat; they appeared, however, to wear well.

Mr. Scott Russell had tried an India-rubber tube for conveying oil to a revolving crank journal. It was stretched about one-sixth of its length each revolution. The result was that the cohesion was destroyed, apparently by the action of the oil, and it was abandoned.

Mr. Brunel, V.P., observed, that he had known vulcanized India-rubber to bear frequent compression, for a period of five or six years, without any injurious effect being produced. He had no experience as to the effects of tension for a lengthened period; but the rubber was liable to great changes, if exposed to the action of air, sunshine, and light. Its elasticity was then impaired, and he had known it become extremely brittle. It appeared as if the sulphur had been only held in mechanical combination, and was ultimately thrown off.

Mr. E. Humphrys had examined a pair of air-pump valves of a marine engine, made of vulcanized India-rubber, after a twelve months' voyage, and found that they were in perfect order. The valves were 38 inches in diameter, working 36 strokes per minute, upon a metal grating, the bars of which were one-eighth of an inch wide, and the apertures five-eighths of an inch square.

Mr. Hawksley thought, that if the elastic limit of the material was not exceeded, no injury would accrue. He had examined a piston-rod after it had performed one hundred million strokes, and it had suffered no deterioration. Gutta percha, when exposed to the atmosphere, deteriorated faster than India rubber, and after a few years, if unpainted, the substance laminated, and could be rubbed to pieces. Under water, however, it was more durable. Vulcanized India-rubber seemed to absorb heat in contraction, and give it out on distension; this produced an effect called "erema-causis," which eventually caused its disintegration.

Mr. T. R. Crampton could corroborate the opinion just given, as he had found that the gutta percha covering of the wires of the Submarine Telegraph, was very durable under the sea, but on the face of the Dover cliff, where it was exposed to air and light, it had soon been destroyed. It was then buried under ground, and had proved perfectly successful.

Mr. W. Brockedon, through the Secretary, called attention to a vulcanized India-rubber valve, in which the disc of rubber was allowed to rotate, and thus change the points of pressure, instead of being fixed as formerly, when it was compelled always to beat in the same place. He thought that in the vulcanized India-rubber valves mentioned, as not having been found "to diminish the shock of the beat," there must have been a disproportion between the area of the openings, the width of the grating-bars, and the thickness of the India-rubber disc, or slab. Engineers were not agreed on these points. The openings in the valve beds varied from 1 square inch to 6 square inches in area, and the width of the bars from $\frac{1}{8}$th to $\frac{5}{8}$ths inch. The thickness of the rubber also varied from $\frac{3}{8}$ths to 1 inch. He thought that for a valve of 20 inches diameter, the opening in the bed-plate should be about $1\frac{1}{4}$ inch long, and 1 inch wide, and the width of the grating-bars about $\frac{5}{16}$ths inch. The disc for such a valve should be about $\frac{3}{4}$ inch thick. He believed that valves with something like these dimensions, and with proper precautions for the escape of air, which was always accumulating in pumps, and which, if retained, caused much concussion, would work easily and quietly. At Manchester, a new foot-valve had recently been put to an engine, in which the only materials used were cast iron and vulcanized India-rubber. There was no brass, and yet it was working perfectly. The brittleness of vulcanized India-rubber was not always produced by air and light. It depended in some degree upon the relative quantities of rubber and sulphur—the degree of heat and the time employed in effecting the change—and the further change which time and circumstances might produce upon it. In cases where it was known to what use, and to what degree of exposure, the rubber would be subjected, carbon had been combined with the rubber, as it was known to be a powerful preservative of animal and vegetable substances from decomposition. This effectually protected the caoutchouc from injurious changes, even in tropical climates.

Gutta percha was, in his opinion, far more liable to decomposition than vulcanized India-rubber. It was inelastic, until its temperature rose to 120°, above which its cohesiveness was rapidly lessened up to 140°, when it was as easily separated as wet paper. It could, however, be reunited, was plastic, and could be moulded into any form, in which it would set and become

rigid again as it cooled. Gutta percha could not be vulcanized alone, nor could it acquire any of the properties of vulcanized India-rubber; but it might be combined with India-rubber, like any other material, to adulterate, or change the quality, and like such compounds it could be vulcanized. In this case the vulcanization was due solely to the India-rubber, and the compound was deteriorated for every purpose in which elasticity was required; and in which strength, at even moderately high temperatures, was necessary.

Mr. RENDEL,—President,—suggested, that an interesting series of experiments might be made, on the duration of the elasticity of vulcanized India-rubber; as that substance, as well as gutta percha, appeared to be eminently adapted for use in engineering operations.

April 19, 1853.

JAMES MEADOWS RENDEL, President, in the Chair.

No. 890. "Description of the Liverpool Corporation Water-Works." By THOMAS DUNCAN, Assoc. Inst. C.E.

IT is not intended here to trace the causes, which, in many instances, have operated in transforming the village of the eighteenth century, into the thriving and busy town of 1852. Among the wants thus created is the system of furnishing a supply of water, by artificial means, for the use of the inhabitants of a large town, such as Liverpool. A description of the existing works constructed for this purpose forms the subject of the present Paper.

The Government, many municipal bodies, and private companies, have for some time been making exertions to amend the water supply to towns, and to provide new and improved sources; indeed, upon the abundance of the supply of good and pure water may be said, in a great degree, to depend the extent of population and manufactures. Rivers, flowing by, or through towns, when they were small, served to afford the water required for domestic and manufacturing purposes; but the same causes that have rendered a larger supply necessary, have tended to render the water thus obtained, unfit either for domestic use, or for many manufacturing purposes. There are instances where wells, sunk into the rock, have become, after a time, insufficient in yield, arising, it may be inferred, from the gradually-increasing quantity drawn from them, coupled with the extension of buildings and streets covering the surface, and the drainage of the adjoining open country.

The saturation of the ground, or strata, from drains, sewers, &c., in towns, not unfrequently renders the water unfit for domestic use, particularly if the wells are shallow; and when manufactories abound, it generally becomes necessary to sink to deeper sources, in proportion to the extension of the buildings. The general deepening of the wells is followed by a gradual lowering of the water-line, until the expense of sinking becomes

too great for private individuals, and municipalities, or private companies find it necessary, or advantageous, to provide a supply for all the wants of the population.

The great peculiarity of the supply of water to Liverpool consists in its being entirely obtained from wells sunk in the new red sand-stone, and it is perhaps the only instance of so extensive a town deriving its supply of water from such a source.

Works are now in course of construction at Rivington, under Mr. Hawksley's directions, for bringing to Liverpool, from a distance of twenty-four miles, by gravitation, a large supply of water, to supersede the use of wells for the public supply, but it is not intended to enter on the consideration of that undertaking.

The town of Liverpool is situated on the right bank of the river Mersey, a few miles above its junction with the ocean. It extends, with Toxteth Park and Bootle, along the margin of the river, within the Parliamentary boundary, for a length of four miles and three-quarters, by a breadth, varying from a few hundred yards to about two miles.

The lower portion of the town is built upon a number of slight knolls, and is, for about a mile in length, northwards, from about the centre of the length of the river frontage, divided from the upper portion by a valley, running between them, nearly parallel with the river, and distant from it about half a mile. A portion of this valley was formerly the bed of a pool at high water, and received the drainage of the upper districts and eastern slopes of the lower knolls. The southern portion is of a gently-shelving form, rising, for a mile and a half, towards Park Hill. Along the river the rock crops out, and is covered, in most instances, by clay. From Kirkdale, about a mile and three-quarters north of the Exchange, a series of hills commences, sweeping along the eastern side, and terminating at the river, at the extreme south end of the borough, known as Everton, Low Hill, Edge Hill, and Park Hill, the greatest altitude being about 250 feet above the Old Dock cill. The eastern slopes fall towards, and are drained into, the valley of the Brook, which joins the river Alt at about six miles from Liverpool. The only flat piece of surface that is built over within the town, is an area of about a mile in length, by about half a mile wide, below Edge Hill, trending towards the

south, at an altitude of about 160 feet above the Old Dock cill. A portion of this flat was formerly under water, and doubtless assisted in producing the springs which, at an early date, supplied the town below. From Kirkdale to the northwards, through Bootle, the ground is of a gently-swelling form, sloping towards the river. From the river, towards the east, the soil is chiefly of a sandy nature, and in some parts of the town it is of the same character, permeable to water, but in general there is a covering of strong tenacious clay of very variable thickness. In a recent case, where trial borings were made, although the rock was cropping out within 100 yards of the site of the bore-holes, the clay was found to be 26 feet thick. In general, it may be considered as constituting a perfectly-impermeable coating over the rock.

The substratum is the lower new red sand-stone, which dips from the river towards the east and by north at an inclination, generally, of one in six. It extends westwards across the Mersey and the hundred of Wirral, to the river Dee, where the coal formation crops out, at a distance of seven miles from Liverpool. It extends in an easterly direction towards Manchester, and at about five miles distant has its dip in a westerly direction. At about eight miles eastward it is partially interrupted by the Wigan and St. Helen's coal-fields; and it also stretches to the north and south for a considerable distance. The area has been calculated to cover about one hundred square miles. The rock, although in some instances very much shattered, with many faults running east and by south, forms an excellent building material. The stone, near the major faults, in most cases, stands on edge, and is not unfrequently very hard, presenting, when broken, a vitreous, or crystalline appearance. The minor faults are filled up with fine clay, which, in a great measure, prevents the free passage of water; these have been described by geologists as constituting so many water-tight boxes. The thickness of the rock under Liverpool has never been ascertained, but it is known to be more than 600 feet.

About the year 1694, a grant was made by the Corporation to a Company, to supply the town of Liverpool with water, from springs which then rose to the surface at Bootle (about three miles distant from the Liverpool Exchange); but, after possessing the grant for fifteen years, and doing nothing towards ful-

filling their engagements, the Corporation were induced, in 1709, to transfer the privilege to Sir Cleave Moore, Bart., who then owned Bootle Springs, from whence he, also, proposed to derive the supply. Under that gentleman, however, matters went on no better. Nothing was done until about the year 1772, when a gentleman commenced the work, by constructing a culvert, about a mile in length, partly cut in the rock, and partly built of masonry, to convey the water of the Bootle Springs to Liverpool; but the Leeds and Liverpool Canal being about this period in process of formation, and interfering with the project, which does not appear to have been very maturely considered, it was abandoned.

After this period the scheme was permitted to rest until the year 1799, when the Corporation induced a private Company to undertake the supply of the town and port with water.

About this time another Company was formed for a similar purpose, and the two companies were subsequently incorporated; one under the title of the "Bootle Water-works Company," and the other under that of the "Liverpool Corporation Water-works," or the "Liverpool and Harrington Water-works Company."

The works of the Bootle Company were designed, in the outset, by Mr. Telford, and those of the Liverpool and Harrington Company, in their early stages, were designed by Mr. Thomas Simpson, then the Engineer to the Chelsea Water-Works Company.

The Bootle Company appears to have commenced operations, by scooping out a small reservoir close to the springs, at Bootle village, from whence the water was conveyed, by gravitation, to a tank constructed in Vauxhall-road, Liverpool, by elm pipes 8 inches in diameter. It was found that the head was insufficient to give a velocity to the passage of as much water as was required, and a small engine of 2 H. P. was erected at Bootle to force the water to Liverpool. The elm pipes soon became partially choked up, so that, after having been in use for little more than a year, the water-way was found to be reduced to a diameter of 5 inches. Mr. Telford appears then to have broken off his connexion with the Bootle Company, and Mr. Rothwell, from the Shadwell Water-works, was appointed to conduct the works.

After some delay, the Directors agreed, in 1801, to erect an engine of 8 H. P. at Bootle, and to construct a series of cisterns, one over the other, in a building, in Eaton-street, Vauxhall-road; as also an engine, of 15 H. P., to lift the water to the higher parts of the town. The engine at Bootle raised the water from the shallow reservoir alluded to, to the top of a tower there, stated to have been 60 feet high; from thence it passed along the wooden pipes to the Eaton-street Station,* in Liverpool.

Owing to the rapid increase of the population, both Companies appear soon to have been behind the wants of the town. The Bootle Company appears never to have sought their supply from any other source than the springs at Bootle; the works there have, however, from time to time been enlarged.

The Liverpool and Harrington Company appears to have progressed, by adding pumping-stations to the one originally constructed, as the requirements of the town became pressing, until six stations were erected. The original station, in Berry-street, had, however, become dry, and thus, ultimately, there were belonging to this Company only five pumping stations, from which water was distributed for the supply of the inhabitants.

At Bootle three excavations were sunk into the rock, to a depth of 26½ feet, under the surface. Into the bottoms of these spaces bore-holes have been, from time to time, sunk, with more, or less success. The last hole which was sunk, is 6 inches in diameter. It is 200 yards below the bottom of the lodges, and is much deeper than any of the previous bore-holes. It is to be regretted, that no official record was kept of the produce of these bore-holes, nor is there any very correct data, from which to calculate the increase of water obtained; but, from the best available evidence, it has been estimated at about one-fifth of that previously obtained, or about 170,000 gallons per day.

The spaces, or lodges cover an area of 10,048 superficial feet, roofed over. From these the water is conveyed by a tunnel, cut in the rock, to the wells formed under the engines. All the water is obtained from the bore-holes, with the exception of a very trifling quantity from infiltration into the wells and tunnel.

The following is a list of the wells formed by the late Companies, with some other particulars relative to them.

Bootle Station.—This station was constructed at various dates. The height of the surface of the ground above the Old Dock cill is 64½ feet; and the depth of the well, which is 8 feet diameter, and is constructed with cast-iron kerbs, is 50 feet. The length of tunnelling, from lodges to well, is 255 feet. There are seventeen bore-holes of various diameters, and of depths ranging from 13 feet to 600 feet, five being upwards of 300 feet deep, and the aggregate length being 2,702 feet. The present maximum daily yield is 1,102,000 gallons, and the height to which water has been observed to rise, when not acted on by pumping, for the last four years, is 11 feet 9¼ inches.

There are at present three double-acting rotatory engines at this station. The dimensions of these are as follows:—

—	No. 1 Engine.		No. 2 Engine.		No. 3 Engine.	
	Ft.	In.	Ft.	In.	Ft.	In.
Diameter of cylinder	2	10	2	10½	2	10
Length of stroke of ditto	6	0	6	0	6	2
Length of beams—which are of cast-iron single flitch	20	6	20	4½	20	5¾
Length of main centres	0	9	0	8¼	0	8¾
Diameter of ditto	0	6¾	0	6½	0	7
Diameter of air-pumps	2	0	1	9¾	2	1
Length of stroke of ditto	3	0	3	0	3	1

The pumps, which are double-acting bucket and plunger, are of the following dimensions:—

—	No. 1 Engine.		No. 2 Engine.		No. 3 Engine.	
	Ft.	In.	Ft.	In.	Ft.	In.
Diameter of pumps	1	4½	1	4½	1	6¼
Length of stroke of ditto	3	9	3	9	4	0

The pumps deliver their water into air-vessels placed outside on the surface, from whence two mains of 14 inches and 9 inches in diameter pass to the reservoirs at Everton. When working to Atherton-street reservoir the pressure is at 59 lbs. per inch. Only two of the engines are worked at one time.

The duty performed by these engines is 21,554,613 lbs. raised 1 foot per cwt. of fuel, which is a mixture of coal and slack in equal proportions.

Devonshire-place Station.—The engine at this station is worked at high-pressure, and is used for raising the water from

the reservoir there, to supply the tenants along the crest of the hill; it also works into the Church-street reservoir, for a number of hours each day, being shut up for a limited time to the high points above the reservoir.

The diameter of the cylinder is 14½ inches; length of stroke, 6 feet; length of beam, which is of cast-iron single flitch, 20 feet 3 inches; length of main centres, 4½ inches; diameter of main centres, 4 inches.

The pump is double-acting bucket and plunger, 15¼ inches diameter, with a length of stroke of 4 feet.

There are two boilers of cylindrical form, each 20 feet long and 5 feet in diameter. The steam-pressure in the boiler is 35 lbs. per inch. The water-pressure, when working upon the highest ground, is 55 lbs. per inch. The duty done is 15,000,000 lbs. by 1 cwt. of coal.

The following are the stations formed by the Harrington Company:—

Berry-street Station.—Constructed in 1801; became dry and was abandoned in 1831.

Copperas-hill Station.—This station was constructed in 1801. The height of the surface of the ground above the Old Dock cill is 104 feet, and the depth of the well, which is of an oval form, 6 feet 6 inches by 7 feet, is 110 feet. The length of tunnelling is 106 yards. There are four bore-holes, but two only yield water; the diameters of these two holes are 4 inches and 3 inches, and their depths below the bottom of the well, are 38 yards. The present maximum daily yield is 364,000 gallons, and the height to which water will rise when not acted on by pumping is 14 feet.

At the station, there is a double-acting rotatory engine, with a cylinder 27 inches, and a length of stroke of 5 feet.

The main pump is 8¾ inches in diameter, and it works into an air-vessel fixed near the bottom of the well. From this, the water is conveyed away, by a main 9 inches in diameter, and, as at present arranged, communicates with the main laid for the Greenlane Works. The main being at all times open to Kensington, the pressure never exceeds 50 lbs. per inch. The ordinary pressure when working at night to Kensington is 47 lbs. The valves connected with the pumps are of the common butterfly form, made of leather.

The duty done is 21,019,000 lbs. raised 1 foot by 1 cwt. of coal and slack in equal proportions.

Bevington Bush Station.—This station was constructed in 1803. The height of the surface of the ground above the Old Dock cill is $104\frac{1}{4}$ feet, and the depth of the well, which is of an oval form, 6 feet by 10 feet 6 inches, is 149 feet 6 inches. The length of tunnelling is 135 yards. There are three bore-holes, each 3 inches diameter, and of the respective depths, below the bottom of the well, of 58 feet, 64 feet, and 7 feet. The present maximum daily yield is 333,984 gallons, and the height to which water will rise when not acted on by pumping is 45 feet 9 inches.

This engine is single-acting. The diameter of the cylinder is 38 inches; length of stroke, 6 feet; length of beam, which is of cast-iron in two flitches, 22 feet 6 inches; length of main centres, $6\frac{3}{4}$ inches; diameter of main centres, 6 inches; diameter of air-pump, 17 inches; and length of stroke, 3 feet 5 inches.

The pump is of the plunger kind, 11 inches in diameter, with a length of stroke of 6 feet. It is of solid metal, is worked through a stuffing-box, and is loaded by a balance-weight.

The pump delivers its water into an air-vessel at the ground level outside the buildings, and the condensing water is drawn from the main. The valves are Harvey and West's double-beat. The water is conveyed away by a main of 9 inches diameter, which has also been joined to the mains laid from the Kensington reservoir, and from those laid from the Kirkdale and Atherton-street reservoirs.

This engine generally works to Kirkdale during the night, at a pressure of 14 lbs. Formerly when worked through a main of 8 inches diameter, the pressure was 35 lbs per inch.

The duty done is 16,767,000 lbs. raised 1 foot, by 1 cwt. of coal and slack in equal proportions.

Soho-street Station.—This station was constructed in 1825. The height of the surface of the ground above the Old Dock cill is 103 feet, and the depth of the well, which is of an oval form, 6 feet by 8 feet, is 123 feet. The length of tunnelling is 243 yards. There are five bore-holes, one 6 inches diameter, and four 4 inches diameter, and of the respective depths of 256 feet 6 inches, 61 feet, 32 feet, 12 feet, and 14 feet. The

present maximum daily yield is 609,528 gallons, and the height to which the water will rise when not acted on by pumping is 22 feet 7 inches.

At the station there is a double-acting rotatory engine, with a cylinder 30 inches in diameter, and a length of stroke of 6 feet 1 inch. The main pump is 8⅞ inches in diameter, with a double-acting plunger, worked from the beam. It works into an air-vessel near the bottom of the well, and the main from the outside pump communicates with the rising main, through an air-tight column at the surface. The water was originally carried away by mains 9 inches and 6 inches in diameter; recently one main 12 inches in diameter has been laid, which is connected, as at the other stations, with the Greenlane mains. This engine generally works to Kensington reservoir during the night, under a pressure of 55 lbs.

The duty done is 24,652,858 lbs. raised 1 foot by 1 cwt. of equal proportions of coal and slack.

Water-street Station.—This station was constructed in 1828. The height of the surface of the ground above the Old Dock cill is 157 feet, and the depth of the well, which is of an oval form, 6 feet by 9 feet, is 156 feet. The length of tunnelling is 232 yards. There are two bore-holes, one of 4 inches diameter, and the other of 6 inches diameter, and of the respective depths below the bottom of the well, of 180 feet, and 525 feet. The present maximum daily yield is 578,907 gallons, and the height to which the water will rise, when not acted on by pumping is 14 feet 3 inches.

The engine at this station is in almost every respect similar to the Soho engine; the lengths of strokes of the pumps are also the same. The main pump is 12¼ inches in diameter, and 3 feet 11 inches stroke; with double-acting bucket and plunger. The main pump works into an air-vessel placed near the bottom of the well, and the outside pump into an air-tight column similar to that at Soho-street.

The water is conveyed away by two mains 9 inches in diameter, so adjusted, that they can be worked separately, or together. Here also the mains have been connected with those laid for the Greenlane Works, and generally, during three nights in the week, the engine works to the Kensington reservoir, under a pressure of 55 lbs.

The duty done is 19,800,000 lbs. raised 1 foot, by 1 cwt. of coal and slack in equal parts.

Windsor Station.—This station was constructed in 1840. The height of the surface of the ground above the Old Dock cill is 191 feet, and the depth of the well, which is of an oval form, 10 feet by 12 feet, is 208 feet. The length of tunnelling is 198 yards. There is only one bore-hole; its diameter is 4 inches, and the depth below the bottom of the well is 63 yards. This hole was sunk in March 1850, under the direction of Mr. Robert Stephenson, M.P., V.P., and then produced 241,250 gallons per day; the present yield is only 124,996 gallons per day, béing a decrease of 116,254 gallons since it was first formed. Some time previous to this bore-hole being made, a well had been sunk by the London and North-Western Railway Company, for the supply of their works, at Edge Hill. It was found, that the increase noted as having been obtained at Windsor, affected the Edge Hill well, to about half the extra quantity obtained. The present maximum daily yield is 819,500 gallons, and the height to which water will rise when not acted on by pumping, is 69 feet 8½ inches.

At this station there is a Cornish engine, with a cylinder of 50 inches diameter, and a length of stroke of 9 feet; working with steam in the boilers under a pressure of 40 lbs., and cutting it off in the cylinder at 2 feet 10 inches from the top.

There are two lifts to the pump worked by this engine. 1st. A bucket lift, which delivers its water at a height of 72 feet from the bottom of the well. This is 16⅜ inches in diameter, with a 9-feet stroke. The rods are of iron, 4 inches in diameter, and are worked from a set off, from the upper plunger rods. 2nd. The upper lift is a hollow metal plunger, with a wooden rod passed through it, fastened by a bolt, cotter, and plate to the lower end. It is 16⅛ inches in diameter, and delivers its water into an air-tight stand-pipe, rising inside the engine-house. The valve in the drawing lift is of leather, of the butterfly form. The plunger pump has double-beat valves. The water is conveyed away by a main 15 inches in diameter, which is also connected with the Greenlane mains. The engine works at night into the Kensington reservoir, with a pressure of 16 lbs. Formerly the condensing water was allowed to run to waste; but now cooling-ponds have been formed, and

500,000 gallons of water are saved weekly, besides economizing the power necessary for raising it to the surface.

The duty done is 47,521,000 lbs. raised 1 foot, by 1 cwt. of coal and slack, in equal parts. This engine was made by Rigby and Co., of Hawarden.

It has been stated that the Bootle Company formed a series of reservoirs. These are—

1st. At Kirkdale, a circular reservoir, 93 feet in diameter, by 15 feet deep, containing about 617,400 gallons. The height of the bottom above the Old Dock cill, is about 124 feet.

2nd. At Devonshire-place, Everton, a circular reservoir, 78 feet in diameter, by 10 feet deep, containing about 294,720 gallons. This reservoir is covered over with timber, supported on slight cast-iron columns. The bottom is 172 feet above the Old Dock cill.

3rd. At Atherton-street, a quadrangular reservoir, roofed over, with a depth of 16 feet, and containing 703,296 gallons. The height of the bottom above the Old Dock cill is 187½ feet.

4th. At Church-street, Everton, a quadrangular reservoir, roofed with timber and slate, with a depth of 13 feet, and containing about 251,160 gallons. The bottom is 236 feet above the same datum line.

The storing space at Eaton-street was used up to 1847, when, by the fall of the chimney of an adjoining manufactory, it received so much injury, that it was considered advisable to discontinue its use.

There is also a small storing place, provided chiefly for the supply of shipping, at Crosbie-street, which is still used.

The storing space provided by the Company, was at no time greater than for three millions of gallons, all of which, however, was under cover.

The Liverpool and Harrington Company may be said to have relied solely on the system of pumping directly into the mains and services; the accommodation for storing being confined to two insignificant cast-iron cisterns, erected chiefly with a view to the dock supplies, and neither of them containing more than 100,000 gallons.

About the year 1840, a series of conflagrations commenced in Liverpool, by which property, estimated at a large amount, was consumed. Many of these fires, it is asserted, were incendiary.

The deficiency of a supply of water for extinguishing these fires was so severely felt, that throughout the town, an adverse feeling was raised against the Water Companies. Mr. Capes Achlin, the treasurer to the Highway Board and Watch Committee at that time, proposed a scheme for raising salt-water to an elevated reservoir, for extinguishing fires, watering the streets, and cleansing the sewers. The then Highway Board, in whose hands rested the conservation and maintenance of highways, lighting, cleansing, and sewage, were induced to apply to Parliament, for powers to enable them to obtain a more abundant supply of water, for the purpose of extinguishing fires, flushing sewers, and other public purposes. Accordingly a Bill was obtained in the Session of 1843, which empowered the Commmissioners to draw water from the river, or docks, and Mr. James Simpson, President, Inst. C. E., having been appointed Engineer to carry out the works, the Greenlane Works were formed. They were commenced in the summer of 1844, and were brought into operation in the early part of 1847.

In June 1844, a well and working shaft, 38 feet 6 inches apart, were commenced; the former, is 12 feet in diameter for a depth of 28 feet, where it is diminished to a diameter of 10 feet; the latter is of one uniform diameter of 6 feet throughout. The upper portion, which, for 19 feet, is through the clay, and then for several feet in loose rock, is lined with ashler masonry, 18 inches in thickness, set in cement. A drift-way, 5 feet by 4 feet, connects the well and shaft, at 50 feet from the surface; and at 100 feet from the surface a drift is carried down, along with the well and shaft, until a depth of 185 feet from the surface is reached, being 144 feet above the Old Dock cill. Tunnels were commenced to be driven from the shaft at a depth of 157 feet, without any particular plan having been laid down, as Mr. Simpson's instructions were, to follow the direction from whence the water appeared to flow. Tunnelling to the extent of about 400 lineal feet was driven. The tunnels at their commencement are 4½ feet wide; they are, however, gradually increased in width, until, at the bottom of the shaft, they are of the average width of 6 feet. The height at the entrances is 28 feet; they gradually rise upwards in the crown, until, on terminating, they measure 40 feet. Thus a species of air vessel has been formed, which, when the pumping

was commenced, tended to keep the water up at an artificial height. The maximum yield of the well, when the sinking was discontinued, amounted to about 850 gallons per minute, and the cost of sinking was, including the ashler steening, about £6,600.

The engine-house, boiler-house, and tower to contain the stand-pipe and chimney for the boilers, were then erected. The foundations were excavated down to the rock, a depth of 19 feet, and over the entire area of the engine-house, and under all the walls and boilers, which were not excavated so deep, a stratum of concrete, composed of broken sand-stone and Halkin Mountain lime, in the proportion of one measure of unslaked ground lime to six measures of broken stone, was thrown down. The foundation for the cylinder and other parts was carried up in brick-work, set in Halkin Mountain lime mortar, and thoroughly grouted; the walls above the floor line were built of brick-work, with stone dressings, set with the mortar in common use in the locality. The tower is 104 feet in height above the ground line. The roofs consist of iron trusses, covered with slates fastened with copper wire; they are plastered underneath, and the plastering is painted over with oil colour.

A contract was entered into with Messrs. Harvey and Co., of Hayle, Cornwall, to furnish and erect an engine, three boilers, stand-pipe, and two distinct sets of pumps, for the sum of £5,782, including the winch and duplicate working parts. The cost of the buildings was £4,278.

The engine is of the following dimensions:—Diameter of cylinder, 50 inches; length of stroke, 9 feet; length of beam, which is of cast-iron in two flitches, 28 feet 6 inches, (the entablature for the beam is supported by four columns); length of main centres, 12 inches; diameter of main centres, 10 inches; diameter of plunger pump, 17 inches; length of stroke of plunger, 9 feet; diameter of drawing lift, 19⅝ inches; length of stroke of drawing lift, 7 feet; diameter of air-pump, 21¼ inches; length of stroke of air-pump, 4 feet 3 inches; diameter of steam pipe, 10 inches; diameter of steam valve, 7 inches; diameter of top steam, 7 inches; diameter of equilibrium valve, 10 inches; diameter of exhaust valve, 13 inches. All the valves are Harvey and West's patent double-beat valves. In the outset there were no spring beams, the engine being allowed

to strike upon a species of buffer composed of cases of cast-iron, fixed to the longitudinal beams, into which sheets of cork of 2 inches thick, covered over by pieces of oak timber, were laid. This was, however, found to be too rigid, and, after the breaking of one of the main beams, English oak spring beams were introduced, which serve the purpose intended, and since their use no accident has occurred.

The three boilers are each 26 feet long, and 5 feet 9 inches in diameter in the body; there are four flues 13 inches in diameter, extending to the back from the fire-box, which is 7 feet long by 3 feet 6 inches in diameter. The fire-bar space is 14$\frac{3}{4}$ superficial feet, and the water surface has an area of 118 superficial feet. These boilers are set upon cast-iron bearings, formed to the curvature of the boiler, through which the returning flues pass. The flues along the side are 3 feet 6 inches high by 8 inches wide; they are arched over to meet the boilers 3 inches below the ordinary water line. The entire area of heating surface in each boiler is 630 superficial feet. Each boiler is supplied with a separate damper, and a large one is applied to the main flue where it enters the chimney; the whole of the flues are lined with the best fire-brick set in loam. Over the boilers there is a steam chest 30 inches in diameter, with stop and governor valves, each boiler having a separate independent valve 9 inches in diameter, provided with gauge and other cocks. The covering of the boilers is executed in the following manner. One course of half-bricks is set dry, about an inch clear of the plates; the haunches are then filled in with brickwork in mortar; then another course of half-bricks set in mortar is thrown over the top, and over this is spread a layer of 9 inches of ashes, and the whole is covered with Yorkshire flags. The steam chest is encased in brick walls, the spaces being filled in with ashes, and the top covered with rubbed St. Helen's stone. The steam pipe is covered with a double coating of felt, over which is a covering of canvas, encased in beaded woodwork. The cylinder is coated in a similar manner, the steam pipe, the cylinder and cylinder cover being steamed, and the outside casings are of timber and iron. The valves are worked by cataracts, and the whole of the motions are of bright work.

It has already been stated, that there are two sets of pumps attached to the engine, one a drawing-lift, the other worked by

two solid cast-iron plungers, with a rising main of 17 inches in diameter. The plunger pumps are attached to the end of the beam, and are placed vertically over each other. Both sets of pumps are fixed upon African oak beams, let into the rock, and are stayed by oak beams, at different heights, throughout the entire depth of the well. The lower plunger delivers its water into a cistern supported on iron girders, to which the holding-down bolts are attached, and the wind-bore of the upper plunger is fixed. The first length of rods from the top is round; this is attached to the cross-head of the upper plunger, and to another cross-head at 38 feet 7 inches below. From this latter cross-head to the cross-head of the lower plunger, the rods are flat wrought-iron bars in pairs, with cast-iron distance-pieces fitted at the joints, and, at intervals, pieces of wood are inserted, to which the rods are clamped. The balance-box rests upon the top of the lower plunger. Its construction when first put down was faulty, but it has since been altered; the rubbers were originally of willow timber, but these have since been replaced with American oak. Strong catch-beams have also been built into the well, to meet the cross-head at 38 feet 8½ inches from the top, as before described.

A connection has been established between the plunger and drawing-lifts by means of a cistern, placed at the head of the drawing-lift. This is connected with the cistern at the top of the rising main of the lower plunger, so that in case of accident to the lower plunger, the drawing-lift and upper-plunger-lift can be worked together, or the drawing-lift can be worked separately, when it is required to get the water speedily down for the purpose of repairs. The rods of the drawing-lift are 4 inches in diameter, with conically-formed joints, tongues, and sliding rings. Some difficulty was experienced in fixing the pump work, as the water stood at 38 feet from the surface, and the engines employed to keep the water down during the operation of sinking the well had been removed. The drawing-lift had to be slung for a depth of 133 feet below the surface of the water, and the upper portion temporarily stayed in its place, until the water could be pumped out, and the plunger pumps were put down into their proper position.

The stand-pipe is constructed in the following manner:—It is composed, for a height of 76 feet above the engine-house

floor, of two separate pipes 17 inches in diameter, with faced flange joints, having a rebate in the one and a fillet on the other to match; flannel saturated in tallow was placed between the flanges, which were bolted together with inch-and-quarter bolts, the nuts and washers being very strong. The two pipes are placed on a strong cast-iron seating, bedded on solid masonry, and firmly bolted in its place. An oval pipe rests upon and embraces the top of both the stand-pipes, rising to a height of 111 feet above the ground level. The water ascends directly up to the oval pipe on the top of the two pipes, and then falling down the descending leg of the stand-pipe, is led away by a line of pipes 12 inches in diameter, with spigot and socket-joints, to the reservoir at Kensington, which will be hereafter described.

In order to economize water, cooling-ponds were formed. They are constructed as follows:—From the cistern which receives the water from the drawing-lift, and which is provided with sluices, a pipe 18 inches in diameter is carried into the centre of the bottom of the nearest pond. The overflow from the hot well is led into the cistern, in such a way that the hot water is prevented from mixing with that pumped from the well, in the event of the water from the drawing-lift being required to be pumped directly into the town. The water thus conveyed rises, until it passes off down the centre embankment, and again rises in the bottom of the second pond, from the most remote corner of which, and near the bottom, a returning pipe 9 inches in diameter, conveys the water back to the cold-water pump. By this process the water loses 10 degrees of temperature, in passing from the first to the second pond, through the 18-inch pipe leading from the cistern of the drawing-lift. In case of accident, or when the water is required to be got down at a rate quicker than that at which the upper plunger and the drawing-lift can be worked in conjunction, the water is pumped to waste through the cooling-ponds. The rod of the drawing-lift, unless when required for use, is ungeared and laid aside; the operation of connecting, or ungearing occupies about two-and-a-half hours. The duty done is 49,831,672 lbs. raised 1 foot high by one cwt. of coal and slack, in equal proportions.

Whilst the sinking of the well and other works at Greenlane

were in progress, the reservoir at Kensington was formed, and the piping of so much of the town as the scheme embraced was completed.

The reservoir is situated at Kensington, at a distance of 2,700 yards from the well towards Liverpool; the height of the by-wash, at an elevation of 223 feet above the Old Dock cill, with a depth of water of 15 feet. It is formed partly by excavation and partly by embanking; it covers, including embankments, a little over three statute acres, and affords storage for more than 8 millions of gallons of water. The construction of the embankments and slopes is as follows:—

The width of the top of the embankment is 5 feet, the inner slope is 2 to 1, the outer slope 1½ to 1. The width of the bottom footway, to the outside of the coping of the retaining wall, is 6 feet 3 inches. A drain-pipe leads from the centre tank, by which the reservoir can be emptied, for cleansing, or other purposes. The bottom of the reservoir and of that portion of the embankment within the puddle wall, rests upon a bed of puddle, in no place less than 18 inches thick, composed of one-third part of clean screened gravel. The puddle wall is 4 feet thick at the bottom, diminished to 2 feet thick at the top, which is 1 foot below the finished line of the footway. Over the puddle bottom is placed a stratum of broken stone 9 inches thick, increased to 2½ feet at the bottom of the slopes; the surface of the bottom and inner slopes is finished with coursed sandstone pitching, from 6 inches to 9 inches deep. The outer slopes are turfed, and the footway is coated with gravel. The distributing tank has been provided with three pipes—two of 18 inches in diameter and one of 7 inches in diameter. A valve, which is worked from the top by a spindle, is fixed on one of the 18-inch pipes, the other two being stopped up. One 18-inch pipe, and the 7-inch pipe were only carried to the outside of the embankment. Gratings, or screens of copper-wire gauze, are placed in front of the pipes, to prevent impure matter from entering. Ladder bars are inserted in the masonry, for getting down to the valve, and the tank is covered with cast-iron plates. The supply tank was designed to deliver the water at the top water line, from whence it descended, when the water was low, over an invert of masonry, in the angle formed by the meeting of the

inner slopes—the intention being to give motion to the water in the reservoir; but the use of this tank has, for some time past, been discontinued.

It may here be observed, that it has been found impossible to prevent the growth of confervæ, in the water stored in the uncovered reservoirs. Various methods to accomplish this have in vain been attempted—such as keeping up a constant current of fresh water through them, and a liberal use of caustic lime; but so rapid is the growth of the plant, as also the change of colour of the water, that a few hours of bright sun-light have sufficed to spoil several millions of gallons of water. The loss of water, expense of cleaning, and general inconvenience, have directed attention to this subject. Works are now in progress for covering over the Kensington reservoir, and another of somewhat larger dimensions is being constructed adjoining it, which, together with another reservoir upon Park Hill, to be also covered, will afford, when finished, storing space for 21 millions of gallons, perfectly protected from the light.

From the Kensington reservoir, for a distance of 1,700 yards, a pipe 18 inches in diameter is laid into the town, where it branches into two pipes, each of 12 inches in diameter. The pipe, of 18 inches in diameter, is laid for a length of 1,000 yards, in a tunnel, formed under the Prescot Road. The bottom portion of the tunnel forms a duct for the overflow water, which is led by a culvert into the boundary sewer; and by the same channel, any water that may be considered necessary for the flushing of this sewer can also be supplied. When the reservoirs are emptied for cleansing, or repairs, the water is run off by this tunnel. The pipes are supported upon short cast-iron girders, sufficient room being left underneath for a man to pass along in a stooping-posture, for the purposes of inspection, or for repairs.

The sum which the Highway Board was permitted to expend, by the Act authorizing the construction of the works, was inadequate to afford a supply of water, for public purposes, to all parts of the town. Mr. Simpson, the Engineer, was, therefore, compelled to confine the works to that portion of the town where the greatest bulk of inflammable merchandise was stored, and where fires most frequently occurred. As in the Act, the warehouse district was expressly mentioned, the works

were chiefly executed on the margin of the docks, and the district immediately behind them. The mains that were laid were, however, of such diameter as would admit of subsequent extensions. It has already been stated, that from the point where the main of 18 inches in diameter terminated, two branches, each of 12 inches in diameter, are taken off; from these, other branches, of the same dimensions, and of the diminished diameters of 9 inches, 7 inches, and 5 inches, are carried; the latter size is only used in places where the system is considered complete. Each cluster of fire-plugs[1] is controlled by a separate valve, and in most cases consists of three openings, or plugs, at a distance of about five yards apart. They are generally placed at the junction of two, or more streets, so that the water can be more readily applied to any fire occurring near them.

Branches are taken off the mains, at various points, for the purpose of flushing out the sewers. These are constructed as follows:—From the main a short branch is carried, on which a valve is placed, generally 7 inches in diameter. The pipe is then carried by easy bends to the bottom of the sewer, where the water is delivered into it, as nearly as possible in the line of the current. The mains being charged with water, and the valve opened, the water flows into the sewers, and carries along with it all the sediment, leaving the sewer clean.

It has been ascertained, by experiment, that from the drain-tank, at the Kensington reservoir, to Beacons Gutter, a point on the margin of the river near Bootle, the water passes along the entire distance of 19,149 feet in 47 minutes, or at the rate of 6·833 feet per second. The mean inclination between these points is 1 in 95·5, and the general depth of water over the bottom of the invert is 1 foot 10 inches.

Previous to the construction of the Greenlane Works, the water used for watering the streets in summer, was supplied by the Companies into underground tanks, from which it was pumped. The average number of loads distributed by each cart per day was fifteen, and each load measured about 210 gallons. To supply water for watering the streets, hydrants were put down, in sites where the public thoroughfare would be least interrupted whilst filling the water-carts. The number

---

[1] Hydrants are now used instead of plugs.

of hydrants in the first instance was twenty-one. They also served as fire-plugs. From those in the lower part of the town, water-carts were filled, in less than a minute so that 50 loads of water were distributed by one cart, per day, after the opening of the works.

The number of fire-plugs and hydrants laid by the Commissioners, was 465. Although they were not placed at equidistant points, there was one opening to about every 50 yards of pipe laid. The number of plugs and hydrants now laid is 2,289; and as the renewing of the pipes in the town progresses this number will be increased.

Providing an efficient supply of water for extinguishing fires is one, and not the least important, of the considerations which presents itself to all those connected with designing water-works for towns. By an examination of the following table, it will be evident, that the success which has attended the system so well commenced under the Highway Board, has been progressive since the water-works have been placed under the control of the corporation.

TABLE of FIRES.

YEAR.	Number of Fires.	Amount of Property Destroyed.			Amount of Property Saved.			Amount of Cost turning out Engines, &c.			Number of Times Engines Assisted.
		£.	s.	d.	£.	s.	d.	£.	s.	d.	
1840	129	6,128	5	0	161,125	10	0	177	15	0	..
1841	109	7,271	4	0	154,219	10	0	205	3	0	..
1842	140	517,927	12	6	210,506	10	0	677	15	5	..
1843	111	119,584	8	0	127,836	0	0	725	10	4	..
1844	100	44,390	19	6	33,986	0	0	363	15	10	..
1845	89	32,726	18	0	78,333	14	6	423	3	7	..
1846	80	87,869	0	0	77,943	0	0	892	18	5	..
1847*	60	21,385	0	0	49,280	0	0	210	0	0	6
1848	70	20,525	0	0	56,528	0	0	228	8	3	6
1849	56	16,400	0	0	42,000	0	0	189	7	8	7
1850	101	30,640	0	0	157,364	0	0	243	5	10	12
1851	147	26,524	9	6	88,694	0	0	164	16	8	9
1852	132	15,880	0	0	122,704	0	0	101	6	8	6

* Greenlane supply came into operation during this year.

This Table was furnished from the official records of the police establishment, by the kindness of Captain Greig, the head of the force.

The suppression of fires is under the control of the Watch

Committee of the Corporation, a portion of the police force of the borough being specially appointed for that duty. It numbers about 80 men, with one Superintendent, who acts under the orders of the Head Constable. The men also perform the duties of ordinary constables. Until a very recent period, there was only one station for the Corporation fire-engines. This was situated in Temple-court, near the Town-hall. There is also a branch establishment of the West of England Insurance Company, consisting of a few men and one engine.

To render the suppression of fires, by the application of water, as efficient as possible, it is requisite that the supply of water be not only abundant, but facile of application; and also that those whose duty it is to apply the water for such a purpose, should possess the means of doing so, without having to wait until apparatus be brought from a distance—for it is at the outbreak of a fire that its application is most effectual.

The turncocks attached to the water-works render assistance in all cases of accidental fire; but as the greater number of fires occurs between nine at night, and three in the morning, the turncocks are absent, with the exception of the one on duty at the central fire station, and the other at the engineer's office; consequently they have to be called, and cannot of course be of service at the most important moment. Up to a very recent date, when a fire took place, notice had to be forwarded to the central fire station, and nothing could be done until engines, or reels arrived. If the fire occurred where there were no mains, the service pipes had to be filled before any water could be obtained: to do this required the presence of the turncocks, and very frequently much damage was done before water could be obtained. The result, as may readily be imagined, was instant denouncement of all those connected with the water-works, although, in reality, they had little to do with the matter. The Engineer, after remonstrances, reported formally to the Committee, on the absurdity of the practice, at the same time laying down a plan for the improvement and reorganization of the fire police.

The plan proposed by him has been to some extent carried out, and when more fully developed, will put the application of water for the suppression of fires upon an improved footing. The plan is this:—The town has been divided into a certain

number of districts, defined on maps exhibited at all the police stations. The Head Constable appoints men to each district, who are to make themselves acquainted with the pipes, valves, hydrants, &c., of the district, by following the turncock in his daily rounds. In each district, hose, keys, stand-pipes and directors, are placed, so that on the breaking out of a fire, the fire policeman on duty can instantly apply the water, or, if the fire is remote from any main that is charged, being previously acquainted with the pipes, he can turn the water on to the district, and so, at least, have it ready for application, by the time that assistance arrives; and thus before the turncock could be called, the fire may be extinguished. When the supply is constant, the arrangements will be more perfect, and serious conflagrations will, it is hoped, almost cease.

One of the objects in view, in adjusting the works, has been to obtain uniformity in all the appliances. Considerable progress has been made in this; the keys, screws, valves, and indeed the entire appliances, are in every instance, where an alteration takes place, adapted to a uniform standard. Thus, although even if the various descriptions of appliances should not be the best of their kind, uniformity in such matters must be of prime importance, and a mistake will scarcely be possible, when the system becomes complete.

In the session of 1846-7, the Corporation obtained a Bill, authorizing the purchase of the works of the Water Companies, as also the transfer of the powers of the Highway Board. In pursuance of those powers, the works were purchased under arbitration, at the price of £622,000. Mr. R. Stephenson, M.P., V.P. Inst. C.E., acted as arbitrator. On the 1st January 1848, the water-works came under the control of the Corporation; the Green-lane Works having been in the possession of that body, from the 1st January 1847.

From the beginning of 1848, attempts were made to amalgamate the various works, for the general interest of the community, but nothing very effectual was done until 1850; the public, however, had partially enjoyed the benefit of the additional water obtained from Greenlane, to eke out the supply.

Previous to the transfer of the works of the Companies, the Liverpool and Harrington Company pretended to give a daily supply to their tenants, whilst the Bootle Company only sup-

plied their tenants three days in the week. For some time after the transfer had been made, a daily supply was given, but during the summer of 1848, an attempt was made to fall back upon the former system, of only giving a supply during three days in the week, and a general expression of disapprobation was the result; the daily supply was resumed, and was in some measure followed until a recent period.

The Council, during the early part of 1850, instituted several changes in the management, and instructed the Engineer to take into consideration the best mode of arranging the works, so as to render them fit for distributing, by constant service, the water to be obtained from Rivington; as also to make better provision for extinguishing fires. From that period the works designed for these purposes were commenced.

The mains of the former Companies had not been, as it may readily be supposed, laid with a view to future amalgamation. In general, two service pipes and mains, and sometimes a greater number, were to be found in the same street; so that, up to 1850, the turncocks, formerly employed by the old Companies, had, in many instances, to attend to the supply in the same street. Confusion, expense, and waste were thus entailed upon the public, by the complicated condition of the works, for so completely had the system of mains and services degenerated into mere temporary expedients, that no one connected with the establishment could give an accurate account of their course. There were no correct plans, and few upon which the least reliance could be placed, to guide in reducing the tangled web to a system. In some localities the pipes had been, from frequent breakage, so patched and mended, that there was only a very small water-way left. Much of the injury to the pipes had arisen from the sewerage which had been carried forward by the Highway Board. In general, the pipes had been laid in the centres of the streets, the sewers having been formed in the same positions; when these latter were constructed, the pipes were left on an unsound bed, and sank irregularly with the earthwork of the trench. Attempts to prevent this, had been made, by building up, from the crown of the sewer, brick pillars under the sockets. These, however, proved, generally, more fatal to the pipes, than when they had been left to sink with the filled-in-ground, especially to pipes of small dimensions.

The chief difficulties to be overcome, in systematizing the water service, were the great lengths of small pipe, and the irregular manner in which they had been laid. It is easy to imagine how this arose. A portion of a street had, at first, been supplied with water, from the nearest point where pipes previously existed: as the town increased, applications were made for further supplies, at a greater distance; the Companies, badly advised, continued the small pipes onwards, down one street and up another, and so on, until the head required to produce a velocity sufficient for the passage of as much water as was required through the remote portion, told fearfully on the engines, pipes, and expenditure of the Harrington Company. This state of things had given rise to a mass of expedients, that ultimately became very perplexing to that Company.

No regularity had been observed either in the lines, or in the levels; the pipes might be set out fair at one end and side of a street, but by degrees they would be carried to the centre, then again over to the other side. This had been occasioned, doubtless, from the pipes being laid piece-meal, to meet the wants of the inhabitants, as new streets became populated. As to level, it appears not to have been considered worth attention, whether the water was supplied up-hill, or down-hill. To meet this state of things, the Engineer resolved to divide the town into sections, commencing at the lower portions of the town; and whenever, on examination, the existing pipes should be found sufficiently large, to allow them to remain. Thus the major part of the system has been formed into an independent series of water-works, capable of being worked together, or singly.

But there were still other evils to be remedied, by which the pipes had, in some localities, been rendered nearly useless. In all parts of the town in which lines of pipes had been laid by both the old Companies, when an inhabitant either for his own advantage, or from caprice, desired to change, and to be supplied by the other Company, he was gladly received. Frequently he was allowed to select the size of the pipe to be laid to his premises; so that lead pipes of an inch, and an inch and a quarter diameter were frequently laid down for a domestic supply. The iron pipes were thus injured, by being pierced by such large holes, and of necessity the pipe from which the

supply had formerly been obtained, required to be plugged up. This had been done in the most slovenly manner, viz., by driving wooden plugs into the ferrule-holes; and in nearly every instance these plugs were projected far down into the pipe, in some cases passing almost across the diameter. The water-way, therefore, became much impeded, especially as every bit of solid matter which might be carried along was caught by these projections; and the pipes were thus rendered unfit for the purposes intended. These changes occurred so frequently, that several holes so filled up, have been found in the length of a single yard of pipe, for the old holes were rarely used, when a tenant returned to the original Company for a supply.

The mains laid for the Greenlane works have been incorporated and made available, so far as they extended throughout the lower portions of the town; so that at present the mains over a considerable extent have been reduced to a system, the basis of which is as follows:—Two, three, or more streets, are laid off as one service; the outlet from the main is commanded by one valve; the lengths of the small pipes have been reduced; and in general they have been relaid on the side of the street, at a distance of from 1 foot to 3 feet from the kerb-stone. Hydrants have been placed along the lines of services, at the ends of the pipes, and generally near the eye of a sewer; the old plugs have been removed, or have been transformed into hydrants. Two points of communication, from different mains, have been established to each block, or service, so that the supply can be constantly maintained, supposing a portion of the main to be under repair, or in the event of a larger demand than ordinary being required, for extinguishing a fire in the district: by supplying the services from two points, the pressure can be better maintained, whilst the velocity through the pipes is not unduly increased. In the wide streets and busy thoroughfares, a line of service pipes has been laid along each side, so that there are no pipes crossing the streets. The pipes are thus out of the way of the sewerage, or other works, and are more secure from the effects of vibration and injury from the traffic. The standard depth below the surface has been fixed at 2 feet, from the upper side of the pipe.

The supply pipes from the services are of lead. It has already been stated, that it was not unusual to lay down for the

house supp y, a pipe one and a quarter inch, one inch, or at least three-quarters of an inch diameter, weighing 11 lbs. per yard. This practice has been discontinued, and to no dwelling-house, except on the highest portions of the town, are pipes now laid of a greater diameter than three-eighths of an inch, weighing $4\frac{1}{2}$ lbs. per yard, as from a carefully-conducted series of experiments, pipes of this diameter have been found sufficient. To cottages, pipes of a quarter of an inch in diameter are laid, and fulfil all the purposes required. The experiments, on which the size of pipes for the domestic supply have been based, are given in the Appendix (page 501).

The weights, and consequently the strengths, of the various pipes laid are regulated thus. On a contour plan, kept in the office of the storekeeper, lines are drawn dividing the town into two heights, to each of which pipes of certain weights are allotted; so that when an order for pipes is delivered, the storekeeper looks at the map, to ascertain on which side of the line the pipes are to be laid, and delivers accordingly; this practice has been invariably maintained for the last two years.

Until about two years ago, the brass ferrules were of the ordinary driving kind; but when the pipes were subjected to a steady pressure, for a length of time, there was considerable leakage, and the ferrules were liable to be blown out. This had been unsuccessfully attempted to be remedied for some time. Those now used, however, meet every condition required. No solder is used, they are as cheap as the old ones, and are easily attached, having at the same time the advantage of perfect security. The practice of filling up holes left in the pipes, by iron screw plugs with shoulders, to prevent their projection into the water way, has also recently been adopted, and wooden plugging is abandoned; the average cost of each plug and its insertion is $2\frac{1}{2}d$.

Meters have recently been introduced, for regulating the supply to manufactories, and generally, wherever they have been fixed, they have been found to give satisfaction. An intermittent supply is however unfavourable for their introduction, but whenever the supply is constant they are unquestionably preferable to any other mode of adjusting the water rent. Those in use in Liverpool are made by Parkinson, of London. They belong to the Corporation, and are rented by the con-

sumers of water according to the cost; they range in capacity from 200 gallons per hour to 1,200 gallons per hour.

The great number of ships frequenting the port, and the consequent extent of accommodation required, renders the supply of water to shipping a matter of considerable importance. This will be admitted, when it is stated, that the revenue for the year 1852 amounted to £9,600. The pipes, ranging in size from 3 inches to 6 inches in diameter, extend around each dock. Those which had been laid along, and around the dock quays, by both companies, were, until a recent period, in most instances, complicated and in bad condition.

The double lines of pipes, and the imperfect state of the plugs, caused much waste of water on the quays, risk of damage to goods, and loss of time. A better method of supply was decided on, and plans for renewing the pipes round the docks, coupled with a recommendation for transforming the old plugs into hydrants, were approved by the Committee. The double lines of pipes have been taken up, the pipes adjusted, and hydrants have been placed upon the old plugs.

The supply to ships was formerly, and is still to some extent, given in the following manner: into one of the apertures, which, when not in use, is closed by a wooden plug, a stand-pipe of copper, generally about 3 feet long, is inserted, the lower end being wrapped around with yarn, so that it may fit tightly and prevent leakage. The top of the stand-pipe is fitted with a cone cock and screwed nozzle, to which a leathern hose is attached, to be carried on board the ship to be supplied. With the new hydrants a short copper tube is screwed on; to this the hose is also screwed, and the valve is worked by a light key—the whole operation not occupying one minute, and loss of water is prevented.

The works have been re-arranged and completed from the extreme north-end of the docks to the Custom-house, a distance of two miles and a half, and a continuous line of pipes now extends along the docks, for that distance, chiefly under the sheds, as also along all the quays. These are fed by branches from the mains in the streets, running parallel with the quays, and the supply is regulated by valves, so that the water may be shut off from any dock, without inconvenience to that next to it. The distance of the pipes, generally, from the quay

line, is 15 feet, and the distance between the hydrants is 50 feet. On nearly all the quays there are two lines of pipes, running parallel with the dock-wall, cross pipes being avoided as much as possible. The pipes are usually carried to the quays, on the river side of the docks, through the bottom of the locks, and in some recent instances, Mr Hartley, the Engineer to the Docks, has provided tunnels, to contain both the water and the gas pipes.

Two years ago there were employed in the dock supply, two superintendents and twenty turncocks; there are now only one superintendent and fourteen turncocks. A cask containing 120 gallons can now be filled in two minutes. The cost of a hydrant fitted with its box, is £2 6s. 6d.

Various materials have been tried for the hose for the dock service, viz.: copper riveted leather hose; canvas hose; canvas coated with a solution of gutta percha; and vulcanized India-rubber hose; but experience has proved that the 2½-inch copper riveted leather hose is the best for ordinary purposes. The canvas hose chafes rapidly, and is liable to rot; canvas coated with a solution of gutta percha peels, and not unfrequently becomes choked, by the water forming bags in the interior; the like objections exist to the vulcanized India-rubber hose, which is only now used, where it is required to convey water over bale goods, into the holds of vessels. If the makers of hose of this latter description, would take sufficient care in the manufacture, to prevent the plies separating, it would, for all purposes where a dry exterior is a desideratum, be more suitable than leather, as it can be made of any required length, without joinings.

During the process of taking up and adjusting the pipes in the lower districts, near the margin of the docks, where the soil is impregnated with muriate, they were found, in many instances, to have become so soft, that they could easily be cut by a knife. This was found to be the case where they had not been laid for more than twenty years; whereas, in the higher districts, where they had been laid for nearly fifty years, they were found to be as good as when first laid down. In all instances the hardest pipes had deteriorated least, and were found cleanest on the inside.

The loss of length consequent upon taking up, cleaning, and

fitting the old ferrule-holes, with iron-screw plugs, has been found to be in the following ratios :—Loss upon pipes 2 inches and 2½ inches in diameter, 45 per cent. Loss upon pipes 3 inches in diameter, 40 per cent. Loss upon pipes 4 inches in diameter, 38 per cent. Loss upon pipes 5 inches in diameter, 35 per cent. Loss upon pipes 6 inches in diameter, 9 per cent.

The trench work is performed by contract, at the following rates, viz. : for old pipes, including taking up the paving, excavating the trenches, filling them in, ramming, repaving, and maintaining the trenches for six months, and delivering them up perfect, at the rate of (all pipes from 3 inches to 9 inches in diameter, trench 2 feet deep) 6*d.* per lineal yard; the pipes being taken out of the trench and carted away by the Corporation.

For new works, average depth of trench 2½ feet, pipes from 3 inches to 7 inches in diameter, maintained as above, at 8*d.* per lineal yard; the pipes being carted to the street and laid by the Corporation.

In a few instances, short lengths of the old wooden pipes have been found, generally in good preservation. Some of these had been laid for nearly fifty years; all the service-pipes were originally of elm timber.

The increasing demand for water induced the Water Committee, on the recommendation of the Engineer, to enter into contracts for erecting an additional engine at Greenlane. In the latter end of 1850, a contract was accordingly entered into with Messrs. George Forrester and Co., to erect and finish an engine and additional buildings at Greenlane, for the sum of £5,750. This work was completed in April 1852.

The working shaft formerly sunk was fixed upon as the new well, and by widening it, a sufficient space was obtained for the pit-work, as also a way to lower into, or hoist out any material that might be required. No ladders are fixed here, and the way has been left perfectly clear. Men, or materials, are lowered, or raised, by the winch. The upper portion has been lined with 9-inch brick-work, set in cement; the remaining portion, until it falls upon the top of the connecting tunnel, is cut smoothly out of the rock, thus forming a clear uninterrupted passage to the bottom of the well.

The foundations for the engine-house were excavated to the

rock, and the space from thence to the man-holes for the holding-down bolts, was filled up with concrete, formed in the same proportions of broken sandstone and Halkin Mountain lime, as has already been described. The other portions of the foundations, with the exception of the covering over of the man-holes, the bases for the cylinder, and the columns for supporting the entablature, are of brick-work.

The walls above the foundations are of brickwork with stone dressings; the roofs are of iron, slated and finished like the old engine-house. The space between the old and the new engine-houses is covered with glass laid on iron rafters; and the floor is laid with rubbed Yorkshire flags, uniform with the engine-house formerly erected. The two lower tiers of windows in the old engine-house, next to the new buildings, have been cut down to the floor line, to afford better light and communication in the establishment.

The following is a brief description of the new engine:—

The diameter of the cylinder is 52 inches; the length of stroke of the cylinder is 9 feet; the length of stroke of the pump is 9 feet; the length of the beam, which is of cast iron in two flitches, is 28 feet 9 inches; the length of bearing of the main centres is 15 inches; the diameter of the main centres is $10\frac{1}{4}$ inches; the diameter of the plunger is 19 inches; the diameter of the air-pump is 27 inches; the length of stroke of the air-pump is 4 feet 6 inches;[1] the diameter of the steam-pipe is 9 inches; the diameter of the steam-valve is 8 inches; the diameter of the top steam-valve is 8 inches; the diameter of the equilibrium-valve is $10\frac{1}{2}$ inches; the diameter of the exhaust-valve is 14 inches. The cylinder and cylinder cover were finished like the old engine, with similar fittings and casings.

There are three boilers, each 26 feet long, and 5 feet 9 inches in diameter; with three flues, each 17 feet long, by 14 inches in diameter; the fire-bar space is $17\frac{1}{2}$ square feet; the heating surface is 580 square feet; and the water surface is 118 square feet.

The boilers and steam-chest are covered and finished similar to those of the engine previously erected. The motions are

[1] This was increased beyond the usual proportions; and the result, compared with the old engine, by Harvey and Co., is very favourable.

finished bright work, and the valves are similar to those of the previously-erected engine.

The pumps, in this instance, rest upon the rock at the bottom af the well; the clack-piece is seated upon two beams of African oak, 32 inches by 14 inches; and the pumps are stayed throughout to the top by beams of English oak. The ascending main from the lower plunger is 19 inches in diameter; it is in lengths of 9 feet each, with faced flange joints, having a fillet on the one and a rebate in the other; tarred flannel is placed between the flanges, which are firmly bolted together.

The balance box is placed, as in the former arrangement, upon the top of the lower plunger, immediately over the cross-head. Some difficulty having been experienced in the former case, by the conical form of the rod, where it passed through the plate forming the bottom of the balance-box, jamming and splitting the plate upon two occasions: this has been avoided, and hitherto it has stood unmoved and perfect.

Previous to lowering the new pump into its position, it was found necessary to remove a quantity of rubbish which had accumulated immediately in the place to be occupied by it. After several attempts to remove it by a species of dredging, recourse was had to diving. Divers were obtained, who in twenty-one days, cleared a space sufficient for the seating of the pump work, which was lowered into its place; the cost of this operation was £150, and the depth of water in the well during the operation was 26 feet.

When the pumps were fixed and at work, it was considered advisable to clear out all the rubbish from the bottom of the well, and by the greater power of the new engine, the water was got down to 2 feet 6 inches, below the top of the windbore. This was accomplished by filling up the holes with plugs of wood, the holes having been purposely cast tapering. The water being kept at a depth of 4½ feet, the bottom of the workings were thoroughly cleaned out.

The pumps previously fixed and attached to the old engine were then lowered, the lower clack and main bearers to a depth of 13½ feet, and the windbore 4½ feet, so that it now rests upon the bottom. The number of blast-holes was increased twofold, so that the water-way was nearly doubled. These alterations have been improvements, as is now evident by the easy motion

of the valves, for since the alterations have been completed no adjustment has been required; previously these demanded close attention, especially if the speed of the engine had to be increased. Two firemen and one engineman are employed on each shift; they clean the house and the engine, and one engineman is held responsible to the engineer, or station superintendent, for the proper trim of the establishment. The duty done is 57,800,000 lbs. raised 1 foot by one cwt. of coal and slack in equal parts.

At this point a few observations on pump valves may be interesting. From observing the working of the various descriptions of valves employed in the Liverpool Water Works, the following conclusions have been arrived at.

When the water to be pumped is clear, and chips, or other solid matter, are prevented from entering the pump, the double-beat valve, known as "Harvey and West's," or some modification of its form, has been found to answer better than any of the other kinds used. The wooden seatings, in most cases, have been removed, and gutta-percha seatings inserted, which have been found to wear better than wood, or block tin. The chief desiderata of pump valves are considered to be:—ample water-way, with the least possible lift—freedom of action—non-liability to stick fast—as much lifting surface only, as is requisite to lift, without interfering with the required water-way, and not so large as to cause the valve to strike heavily in falling—no greater weight than is required for strength to resist the strain to which they are to be subjected—and lastly they should be easily accessible for repairs. When, however, works are in progress and Cornish engines are employed, and where it is difficult to prevent chips and other matter from entering the pump, the use of Harvey and West's valve is attended with danger. In such cases the more simple the form of the valve the better. It will be found advantageous, therefore, to employ, temporarily, simple flap valves, and when the risk alluded to no longer exists to fit in the valves of more perfect construction.

The best mode of fitting and gearing buckets in large pumping establishments deserves some attention. Until within a comparatively recent period, the buckets (where the valves were not metallic) were fitted up with leather. Nearly every description of this material at all likely to answer the purpose was tried, but with each the expense and loss of time were so great, that a

different material was considered desirable, and gutta percha was employed. This material was tried pure, but failed to be satisfactory; the engine superintendent then made some experiments by mixing black lead with gutta percha, and the result has proved perfectly successful. The buckets are now wholly fitted with this mixture, which is put into the lathe and turned to fit. There is no waste, as the turnings are preserved and mixed up with fresh material, for the fitting of the next bucket requiring repairs. The proportions for the mixture are seven parts of gutta percha to one of black lead. The saving thus effected is at the rate of 100 per cent.

The annexed tables of the cost of pumping, in Liverpool, may be relied upon, as fair examples of the cost of raising water, under similar circumstances. (*See Tables, page* 493.)

The cost of coals, as will be observed, forms a considerable item, in the expense of raising water by pumping. They are supplied by contract. In order to form a correct estimate of the evaporative values of the different descriptions tendered for, careful tests were instituted, of which the results are given in the following table. (*See Table, page* 494.)

The prices paid Messrs. Barton and Windus, No. 3 in the second part of the table, are as under:—

Bootle Station—coals, 6*s.* 10*d.* per ton, and slack, 3*s.* 8*d.* per ton, which being used in equal proportions gives a mean of 5*s.* 3*d.* per ton. At Greenlane, the cost is, for coals 8*s.*, and slack 5*s.*, giving a mean of 6*s.* 6*d.* per ton for the mixture. At all the other stations the prices are, for coal 7*s.* 6*d.*, and slack 4*s.* 6*d.*, giving a mean of 6*s.* per ton for the mixture.

All the coals tested (excepting the Welsh coal) were from local fields, near Wigan.

When an additional engine at Greenlane was recommended to be erected, it was suggested that a bore-hole should be put down in the bottom of the workings, on the assumption that an increase of from three to four millions of gallons of water per week would be obtained. As soon, therefore, as the lowering of the pump work of the original well had progressed sufficiently, boring was commenced, a contract having been entered into for its accomplishment, based upon a progressive scale, changing at every 20 yards in depth, viz., for the first 20 yards 50*s.* per yard, the second 60*s.*, the third 70*s.*, and so on, adding 10*s.* for every 20 yards. The diameter of the hole was 6 inches.

COST of PUMPING at the different STATIONS of the LIVERPOOL WATERWORKS.

Name of Station.	Number of Gallons.	COST PER MILLION GALLONS. Coals.			Stores.		Establishment.			Repairs.			Total Cost.		
		£.	s.	d.	s.	d.	£.	s.	d	£.	s.	d.	£.	s.	d.
1850.															
Bootle . . .	337,034,851	1	16	8¾	4	3½	0	15	11⅛	1	4	1¾	4	1	2¼
Bush . . .	105,743,505	3	5	2½	7	6	1	18	6	2	12	7½	8	3	10¾
Soho . . .	207,676,618	2	1	3¼	6	3¾	0	17	9½	0	10	3⅛	3	15	7½
Hotham Street.	75,686,683	2	19	1¼	9	7½	1	15	8⅛	1	18	1¼	7	2	6¾
Water Street .	156,821,129	2	14	11¼	11	10½	0	18	10	2	14	5¾	7	0	1½
Windsor . .	308,771,611	1	9	11½	4	8¾	0	17	9¼	1	12	5¼	4	4	10½
Greenlane . .	391,258,296	0	19	10¼	4	7	0	16	3	0	8	5¼	2	9	2
Everton . . .	85,903,480	1	18	8¼	4	8¾	1	6	1½	0	17	10½	4	7	5
Totals and Mean Costs . . .	1,582,492,693	1	18	8¼	6	2¼	1	0	9¼	1	6	6¾	4	12	8¼
1851.															
Bootle . . .	340,313,080	1	3	5¾	4	9¼	0	15	8¼	0	12	2¾	2	16	2
Bush . . .	112,833,378	2	8	8	6	1	1	13	5½	0	8	10	4	17	0½
Soho . . .	193,768.277	1	15	0½	5	0	0	19	10	0	8	0½	3	7	11
Hotham Street.	90,876,075	2	11	3¾	8	0	1	6	7¼	1	2	10½	5	8	9½
Water Street .	162,512,635	1	19	10¼	6	10	0	19	7¼	0	15	7	4	1	10¾
Windsor . .	321,452,060	1	0	8¾	4	3	0	14	7½	0	10	7¼	2	10	2½
Greenlane . .	422.279,997	0	19	10	2	10	0	13	9¾	0	4	8¼	2	1	2
Everton . . .	72,588,180	1	14	11½	4	10¾	1	9	3	1	0	6	4	9	7
Totals and Mean Costs . . .	1,644,035,502	1	9	9¾	4	10¾	0	19	0¼	0	11	1	3	4	9
1852.															
Bootle . . .	340,084,750	1	4	7¼	4	3½	0	15	3¼	0	9	1¾	2	13	4
Bush . . .	103,333,083	1	19	3¾	4	9¼	1	15	4¾	0	7	6¼	4	7	0
Soho . . .	180,540,544	1	11	4¼	4	10	0	19	6¼	0	11	0¼	3	6	9
Hotham Street.	93,174,615	2	1	5	5	5½	1	6	10¼	0	6	7¼	4	0	4
Water Street .	159,989,275	1	18	0½	5	2¼	0	19	3½	0	7	5½	3	10	0
Windsor . .	303,690,000	0	18	2½	4	0	0	14	9	0	5	6½	2	2	6
Greenlane . .	669,971.095	0	17	4¼	3	9⅛	0	10	6¾	0	14	6¼	2	6	2¾
Everton . .	79,329,000	1	10	3½	4	5¾	1	5	6¾	0	15	6¾	3	15	11
Totals and Mean Costs . . .	1,850,783,362	1	5	8½	4	5½	0	17	0½	0	10	11½	2	18	2¾

RESULTS of Trials of COAL and SLACK tested at GREENLANE STATION.

AUGUST, 1850.

Name of Coal Proprietor.	Duration of Experiment in Hours.	Material used. Coal in Cwts.	Material used. Slack in Cwts.	Work done. Strokes made by Engine.	Work done. Lbs. lifted per Stroke	Work done. Mean Lift in Feet.	Duty. Lbs. raised 1 Foot high by 1 Cwt. of Coal and Slack.	Mean Temperature. Cistern.	Mean Temperature. Hot Well.	Correction due to Colder Injection. Water-Datum 118° Hot Well.	Comparative Duty in Millions of lbs.	Ratio of Values.	Total Ashes from each Experiment, in lbs.	Proportion of Ashes to Coal.	Degree of Expansion.
J. A. Case	72	86	86	39,114	835	245·34	46,586,343	77·16	118·	..	46,586,343	100·	1,227	6·36 to 100	·428 to 1·000
Byrom, Taylor, and Byrom	72	88	88	39,192	835	247·1	45,945,605	77·28	11·	73,512	45,872,093	98·46	1,477	7·49 „ 100	Ditto.
Bromilow and Co. . . .	72	88	88	39,121	835	245·25	45,519,006	77·28	117·14	107,480	45,411,526	97·47	1,403	7·1 „ 100	Ditto.
W. Harding	72	100	100	39,085	835	245·46	40,023,388	73·75	114·37	405,436	39,618,952	85·44	1,221	5·45 „ 100	Ditto.
J. Powell (Welsh Coal) .	72	122	..	39,040	835	246·	65,731,200	76·	114·	725,672	65,005,528	141·68	924	4·94 „ 100	Ditto.
Ditto ditto .	24	22½	22½	13,039	835	246·42	59,953,380	77·	115·3	446,652	59,506,728	127·73			

AUGUST, 1852.

Name of Coal Proprietor.	Duration of Experiment in Hours.	Material used. Coal in Cwts.	Material used. Slack in Cwts.	Work done. Strokes made by Engine.	Work done. Lbs. lifted per Stroke	Work done. Mean Lift in Feet.	Duty. Lbs. raised 1 Foot high by 1 Cwt. of Coal and Slack.	Mean Temperature. Cistern.	Mean Temperature. Hot Well.	Correction due to Colder Injection. Water-Datum 118° Hot Well.	Comparative Duty in Millions of lbs.	Ratio of Values.	Total Ashes from each Experiment, in lbs.	Proportion of Ashes to Coal.	Degree of Expansion.
1. Blundell and Co. . . .	63	90	90	33,360	835	259·25	40,119,801	86·	118·	..	40,119,801	100·	1,358	6·73 to 100	·5 to ·10
2. Harding	60	83	80	31,980	835	263·	43,085,692	81·5	116·	236·774	42,848,918	106·80	1,199	6·56 „ 100	Ditto.
3. Barton and Windus . .	69	90	90	36,990	835	264·75	45,429,114	81·5	116·	249·651	45,179,463	112·61	1,153	5·71 „ 100	Ditto.
4. William Hulton . . .	65	90	90	33,730	835	265·25	41,503,593	78·	110·5	855,744	40,647,849	101·31	2,025	10·04 „ 100	Ditto.
5. Bromilow and Co. . . .	62	90	90	31,920	835	264·25	39,128,378	78·	111·	752,468	38,375,910	95·65	1,782	8·83 „ 100	Ditto.
6. Earl of Balcarres . . .	63	93	94	32,950	835	263·916	38,829,876	80·3	113·66	462,260	38,367,616	95·63	,672	7·98 „ 100	Ditto.
7. Ince Hall Coal Company .	65	92	90	32,580	835	263·583	40.608,147	84·5	118·	..	40,608,147	101·21	704	3·45 „ 100	Ditto

The quantity of water yielded by the well, previous to the commencement of the bore-hole, was found to be, after working at a low level for several weeks, 835 gallons per minute—a yield considerably less than had been ascribed to this well by several experimenters, but in no great degree differing from that ascertained when the well was sunk.

The process of boring was carefully watched, and the gradual increase noted. On boring through five beds, to a depth of 24 feet, an increase of 42 gallons per minute was obtained: on passing through a series of other seven beds, at the depth of 50 feet, making with the former five beds a series of twelve beds, a further increase of 45 gallons per minute was obtained. No further increase was obtained, until after passing through a bed of 7 feet 10 inches in thickness, and one bed of 2 feet 2 inches in thickness, below which was a bed of 6 inches of rubble matter, which yielded at first very little additional water. On resting at this point the water was observed to rise suddenly, and to be of a perfectly clayey colour: in fact, the water was found to be so thoroughly discoloured, that all the mains had to be emptied. Since both engines have been at work, it has been found, by careful examination, that this bore-hole yields 1,115,474 gallons per day, in addition to the former produce of the well—a result somewhat at variance with previously-advanced theories. To check the flow of water through the bore-hole, at such times as it might be necessary to stop either of the engines, the mouth of the hole has been widened out to a conical form, and an oak beam has been formed to fit it. The beam is fixed in guides, from which rods are carried to a height of 60 feet above the bottom of the well; the rods are worked by a strong screw, by which the beam can be lowered, or raised at pleasure, thus affording time for effecting any repairs that may be required to be done below.

At the outset, it was feared that the flow would not be continuous, and that other wells belonging to the Corporation would be drained; but as yet no indication of this is perceptible, as no change in the yield of any of them can be discerned. Rumours are nevertheless heard, that wells at a distance of several miles southwards, in the direction of Runcorn, have become dry during the past summer.

It was expected that the sudden abstraction of such a large

quantity of water from the Greenlane well, would soon affect a stream of water rising from a bore hole at a distance of $3\frac{1}{2}$ miles in a northerly direction; but after twice visiting this stream, since the augmented volume has been abstracted, no signs of diminution in the yield can be observed.

At this point it may not be improper to revert, for an instant, to the formation from whence the supply of water is obtained. The dip of the strata is nearly towards the east. The valley in which Greenlane is situated, is within two miles from the point where the dip is first observed to be reversed, and it has been ascertained that the thickness of the rock at Bootle is at least 600 feet. If the dip of the rock be carried from the bottom of the bore-hole at Bootle, until it comes under the line of the syneclinal axis passing under Greenlane, it will be found that the thickness of the formation at this point will be, by computation, about 2,000 feet. Further, it is not a very unreasonable hypothesis to assume, that the axis of fracture passes somewhere near to the valley of the Brook, and that the rock, especially in the bottom stratum, has been much dislocated and broken. If this be so, it will be favourable to the passage of water, from very remote parts, to the north and south of the site of the Greenlane works; it will receive the infiltration from the extreme edges of the formation, and form, in the state assumed, a large species of rubble drain, with which some attached channel of the Greenlane bore-hole, has become connected.

The head due to such a velocity as that through the bore-hole, considered as a pipe 6 inches in diameter and 60 feet long, may be set down as that of a column 68 feet high, the velocity being at the rate of 10,874 feet per second.

The question, how much water can be drawn from the wells of a particular district? has frequently been discussed, but has never been satisfactorily answered. The following facts, connected with the Liverpool public wells, may not be without interest, especially when taken in connection with the rainfall of the district, which has been furnished by the kindness of Mr. Hartnup, of the Liverpool Observatory.

RAINFALL in LIVERPOOL for 1850, 1851, and 1852.

Month.	1850		1851		1852	
	Days on which Rain fell.	Depth in Inches.	Days on which Rain fell.	Depth in Inches.	Days on which Rain fell.	Depth in Inches.
January . .	8	1·364	17	3·019	21	2·798
February . .	11	1·109	9	1·602	14	2·698
March . . .	3	0·641	17	2·910	5	0·434
April . . .	17	1·984	12	0·901	2	0·211
May . . .	12	1·486	16	2·105	7	1·433
June . . .	9	0·735	15	3·190	19	2·618
July . . .	14	3·075	11	1·414	10	3·111
August . . .	20	3·139	13	2·743	17	4·518
September . .	9	1·563	6	1·535	11	2·656
October . . .	18	2 665	20	3·582	17	3·666
November . .	17	2·612	13	2·901	23	4·630
December . .	13	1·087	10	0·378	24	3·429
	151	21·460	159	26 280	170	32·202

The public wells are contained within a circumscribing polygon, the area of which measures 8 millions of superficial yards. The maximum daily yield may be set down at 6 millions of gallons; there is, therefore, a yield of ·75 of a gallon per day, for each superficial yard of the circumscribed area: this is equal to a depth of four feet ten inches per annum over the whole area, exclusive of the water obtained from private wells, which may be estimated at two millions of gallons per day.

It has already been remarked that the supply to the inhabitants has, up to a recent period, been intermittent, or daily, the water being on for a few hours only in each district. As the renewal of the pipes has been completed in each separate district, especially since the additional quantity of water has been obtained from Greenlane, the districts have been kept under constant service. This has been done for two important reasons, viz., 1st, to test the pipes; and 2ndly, to test the probable quantity of water required for the whole town, if the supply were to be constant.

The quantity of water delivered, for the three years previous to 1853, has been as under—

1850	. .	1,582,492,693 gallons
1851	. .	1,644,035,502 ,,
1852	. .	1,850,783,362 ,,

In the latter case the increase has taken place since June, 1852, and has been entirely obtained from the bore-hole sunk at Greenlane. About one-fifth part of the town was for some time supplied on the constant system; for several weeks about three-sevenths of the entire population was supplied in the same manner, when it was found, that the quantity of water required under these circumstances, approached so nearly to the maximum yield of the wells, that the area of constant service has been gradually reduced, so as to be within the limit of supply.

The question, as to how much water is required for each individual, under the two modes of distribution, viz., intermittent and constant, has often been asked and disputed. It is believed, that it cannot be satisfactorily answered, as it resolves itself simply into how much is given in the one case, and how much is taken in the other. There will always be a considerable discrepancy in the quantities distributed in different towns, even when supplied by the same method, dependent upon the character and pursuits of the inhabitants, and upon the internal arrangements. It will readily be admitted, that when a water supply is at once brought in upon the constant service principle, the internal fittings will be adapted to the case; whereas, where the constant service has superseded the intermittent, the works will take years to render them perfect, or a greater, or lesser length of time, depending upon the size of the town. The loss of water in all old towns, originally supplied intermittently, will, consequently, be greater, than where the preparations have only just been made, for the reception of a perfectly new supply.

The experience in Liverpool is to the following effect:—For some time previous to the additional supply being obtained, the quantity distributed was 33 millions of gallons per week, with a portion of the suburbs on constant service. If for this constant service 1 million gallons per week be allowed, the quantity stands at 32 millions of gallons per week. For some weeks three-sevenths of the town were upon constant service, when the quantity distributed rose to 41 millions of gallons per week, the difference being 9 millions of gallons per week. From other experiments, calculated as carefully as circumstances would admit, it may be safely inferred, that to supply

Liverpool, by constant service, would require nearly 8 millions of gallons per day, or 20 gallons per day for each inhabitant, the population being taken at 400,000; and if the population of the town continues to increase in the same ratio, a larger quantity than 8 millions of gallons per day will soon be required.

The increase in the number of tenants has been as follows:—

In 1850	. .	1,003 new tenants.
In 1851	. .	1,197 ,,
In 1852	. .	1,977 ,,

This rapid increase is due to the circumstance of the policy of the Water Committee of the Corporation being materially changed since 1850. Some time after the Water-works came under the control of the Corporation, an indisposition was evinced by the Water Committee to extend their works beyond the parliamentary borough; but now large and populous suburban districts have been added to the area formerly supplied with water from the Liverpool Water-works.

The following observations on the flow of water through the main leading from Greenlane to Kensington may be of interest.

At first the main was 12 inches in diameter throughout, being joined to the stand-pipe at one end, and left open to the top of the reservoir at the other. Its length was 8,160 feet. There were six bends—three vertical and three horizontal. Two of the vertical bends were at angles of 90°, and one of 140°. Two of the horizontal bends were at angles of 140° each, and one of 96°. When the velocity through the pipe was 2·52 feet per second, the observed head was 28·88 feet. Again, when the velocity was 1·64 foot per second, the head was 11·02 feet, and when the velocity was 1·09 foot per second, the head was 4·235 feet. Subsequently, a double line of main 12 inches in diameter was laid for a length of 1,695 feet; both lines were then inserted into one of 12 inches diameter, and when the velocity was 2·7 feet per second, the observed head was 25·53 feet. Ultimately the two mains of 12 inches diameter were joined to one main 18 inches in diameter, for a length of 30 feet, and then enlarges to 36 inches in diameter, for a length of 6,015 feet, from the end of which a short length of 60 feet of pipe, 18 inches in diameter, is laid into the reservoir. When the velocity through the pipe, of 18 inches diameter, was 2·43 feet per second, the observed head was 9·23 feet. These remarks may be of service

to those who are disposed to investigate the theories connected with the passage of fluids through pipes, or other ducts. By comparing the results obtained, from the observations on the main of 12 inches diameter, with Eytelwein's formula, the difference in velocity is a deficiency of 14 per cent.; the whole of this, it is presumed, cannot fairly be attributed to the bends.

This Paper having been already extended to a much greater length than was originally proposed, and the principal objects, in connection with the Liverpool Water-Works having been noticed, it may now with a very few additional observations, be brought to a close.

Owing to the varied level of the surface of the town, it has been considered expedient to carry mains direct from the reservoir to the different levels, so as to make the higher portions independent of those below; but still there is the power of connecting them if desired. There are three different levels, and the three separate divisions of the town are to be supplied from three distinct reservoirs. The formation of two of these is in progress: when they are completed, the power for working machinery, and protection from accident by fire, will be put upon a better footing than at present. It is not enough to have a main sufficient to convey the quantity of water required to any particular district, or point, but in every instance, it will be found desirable, to have the pipes intended to supply water for the purposes of power and extinguishing fires, when in connection with domestic supply, so large, that the motion along them shall be kept as slow as possible, consistent with true economy.

The quality of the water at present supplied from the wells is, with two exceptions, very good. An analysis of three samples from the three principal stations, extracted from Mr. R. Stephenson's Report to the Corporation, is appended (page 502.) The mean temperature throughout the year is 50°.

When the supply from Rivington becomes available, the town of Liverpool will be placed in such a position, as to quantity, that 1,000,000 inhabitants may be located on the right bank of the Mersey, without detriment, or fear, as to an abundant supply of water of the finest quality.

The Paper is illustrated by a series of thirteen drawings, Nos. 4,586 to 4,598, showing the general plan and the chief details of the work.

APPENDIX.

EXPERIMENTS on the FLOW of WATER through LEAD PIPES.

Lead in Feet.	Diameter of Pipe.	Length of Pipe.	Seconds to deliver one Gallon.	CONDITIONS.
	Inch.	Feet.		
8	$\frac{3}{8}$	75	81·560	Straight and horizontal.
2	$\frac{3}{8}$	75	164·000	Ditto ditto.
8	$\frac{3}{8}$	75	83·330	Two horizontal bends near the discharge end.
8	$\frac{3}{8}$	75	81·800	Ditto ditto near the supply end.
8	$\frac{3}{8}$	75	85·000	Four vertical bends near the discharge.
8	$\frac{3}{8}$	75	84·000	Ditto ditto near the supply.
8	$\frac{3}{8}$	27	47·000	Straight.
2	$\frac{3}{8}$	27	105·250	Ditto.
8	$\frac{1}{2}$	48	26·600	Ditto.
2	$\frac{1}{2}$	48	50·620	Ditto.
8	$\frac{1}{2}$	48	26·760	Two horizontal bends near the discharge end.
8	$\frac{1}{2}$	48	26·610	Ditto ditto near the supply.
8	$\frac{1}{2}$	48	27·000	Four vertical bends near the discharge.
8	$\frac{1}{2}$	48	26·830	Ditto ditto near the supply.
8	$\frac{1}{2}$	25	19·700	Straight.
2	$\frac{1}{2}$	25	45·000	Ditto.
8	$\frac{3}{4}$	48	10·000	Ditto.
2	$\frac{3}{4}$	48	20·250	Ditto.
8	$\frac{3}{4}$	48	10·500	Four vertical bends near the discharge.
8	$\frac{3}{4}$	48	10·250	Ditto ditto near the supply.
8	$\frac{3}{4}$	25	7·400	Straight.
2	$\frac{3}{4}$	25	16·900	Ditto.
2	1	30	8·400	Ditto.
2	1	30	8·520	Four vertical bends near the discharge.
2	1	30	8·600	Ditto ditto near the supply.

The above in each instance are the mean results of a number of experiments.

ANALYSIS OF WATER.

Water from Bootle.—No. 1. Lodgment, January 30, 1850. Clear, colourless, inodorous, and tasteless. Scarcely any deposit.

One gallon, by evaporation to dryness, yielded 24 grains of residue, which consisted very nearly of—

	Grains.
Sulphate of lime	3·31
Carbonate of lime	7·10
Carbonate of magnesia	6·93
Chloride of sodium	3·37
Silica	0·48
Organic matter, traces of potassium, and loss	2·81
	24·00

Hardness, according to Dr. Clark's standard, 17·71.

Water from Windsor Station.—About two feet from the bottom lodgment, January 29, 1850.

Clear, colourless, inodorous, and tasteless. Slight deposit.

One gallon, by evaporation to dryness, yielded 23·22 grains of residue, which consisted very nearly of—

	Grains.
Sulphate of lime	0·49
Carbonate of lime	8·70
Carbonate of magnesia	7·43
Chloride of sodium	3·42
Silica	1·20
Traces of organic matter and of potassium, and loss	1·98
	23·22

Hardness, according to Dr. Clark's standard, 17·9

Greenlane Well.—Fifty feet from bottom of well, and four feet below surface of water, January 30, 1850. Scarcely any deposit.

One gallon yielded, by evaporation to dryness, 13·6 grains of residue, consisting very nearly of—

	Grains.
Carbonate of lime	5·26
Chloride of sodium	2·66
Sulphate of soda	2·23
Silica	0·64
Organic matter, and loss	2·81
	13·60

Hardness, according to Dr. Clark's standard, 5·26.

Mr. S. C. HOMERSHAM remarked, on the President inquiring as to the experience of Members, as to intermittent and constant supply, that at Wolverhampton, where the change had recently been made from the intermittent to the constant system, a saving of about 20 gallons per house per diem had been effected. To effect this saving, however, it was requisite that proper attention should be paid to the construction and fixing of the house fittings.

Mr. J. F. BATEMAN said, that a change had lately been made at Manchester, from the intermittent to the constant system, and with this result, that the quantity of water consumed appeared to be in the ratio of 6¼ by the intermittent to 8 by the constant system. It should be remembered, however, that when first introduced there would necessarily be much abuse of the privilege and great carelessness, especially amongst cottagers;—taps would be left open, and water from stand-pipes allowed to run away. An increased consumption of water would, therefore, inevitably take place, at its first introduction; but it was not fair to institute such a comparison at so early a period. He believed, eventually, that water would be economized by that plan. He was glad to hear that so many improvements had been effected at Liverpool; still, he considered, there was yet much to be done. With regard to the fire arrangements at Manchester, he might observe, that they had laid the mains in such a way, that there was now no large block of buildings which was not commanded by, at least, a dozen fire-cocks, so that fire-engines were fast disappearing. The fire-mains were always charged under high pressure, so that fires had now no chance. As a consequence of this, the Insurance Companies were preparing to reduce their premiums. The supply of water was found to average about 20 gallons per head per diem, including several large trade consumers, whose supply was limited, and who paid, in some instances, as much as £1000 a-year for water. This amount, he thought, would be increased to 30, or 40 gallons per head per diem, as the trade supply was capable of great extension. The domestic consumption might be taken at 10 gallons per head per diem. No doubt as baths and wash-houses were increased in number, and cleanliness became more general, the consumption on this latter head would be greater. At present, he believed, it did not exceed that

amount in the manufacturing towns of the North of England. Locality would always influence the result. For trading and commercial cities he estimated, that a total consumption of 30 gallons per head per diem might be calculated upon, as a general rule, but it would frequently run up to 50 gallons and upwards.

Mr. J. Gibbs observed, that the supply of water to be derived from the sandstone varied in different localities. At Wolverhampton it was much less than at Liverpool, though the stratification was in both cases the same. The supply was always greater nearer the sea. It was not safe to generalize from experiments in any one place, and to depend upon getting the same quantity of water from the sandstone in other localities. He thought that 10 gallons per head per diem was too little for domestic purposes. In his opinion at least 22 gallons should be allowed.

Mr. Homersham said, that at Brighton, he had found that 10 gallons per head per diem were quite inadequate for domestic purposes, baths, and watering the roads, even without any trade consumption.

Mr. Mackain believed, that at Glasgow the domestic consumption alone would approach 25 to 28 gallons per head per diem. The actual consumption, including all purposes of trade, cleansing, &c., was about 35 gallons per head per diem. This increased consumption, beyond that of other places, might be due, partly, to the fact, that no charge was made for water for either baths, or water-closets; and, in consequence, shower-baths and water-closets were to be found in the houses of mechanics, whose yearly rent did not exceed six pounds.

Mr. R. Stephenson, M.P., V.P., was not disposed to make any observations on this subject, as it was a question for water-works engineers. But still, as the President had called upon him, and as he had reported upon the water supply to Liverpool, he would offer a few remarks. The effect of the pumping at the Greenlane Works was very remarkable: it had been observed, almost instantaneously, to affect distant wells, and at Edge Hill, some miles distant, this was most appreciable. In some previous experiments in the chalk, he had not found this to be the case. He was not, therefore, prepared for it in the present instance. Wells, in the red sandstone, might be affected at great distances, but he did not think it was safe to argue that all would be so

influenced. The chalk stratum stood alone in its water-bearing capacity. He considered that it was essential to ascertain, with some degree of accuracy, what the proper supply to different towns should be, now that the constant system was coming into use.

Mr. RENDEL,—President,—remarked, that at Edinburgh, which was not a manufacturing town, and where there were not more than fourteen, or fifteen large consumers, the consumption was more than 30 gallons per head per diem. When the change was made from the intermittent to the constant system, the consumption was increased, owing, it was believed, to carelessness and wastefulness; but it was now gradually diminishing, and he had no doubt that, very shortly, the actual quantity used would be less than before the alteration. He could confirm the remarks which had been made as to the results attending pumping from the chalk. At Great Grimsby they were pumping 6,000 gallons per minute from one well, sunk into the chalk, and yet this had not affected another well only 70 yards distant. It would, however, be dangerous to infer, from this single instance, that, in all strata, pumping from deep wells would not affect others in the neighbourhood. This depended, more than upon anything else, upon whether the same fissure was opened up by the wells, and the quantity of water by which the wells were fed.

April 26, 1853.

JAMES MEADOWS RENDEL, President, in the Chair.

No. 894. "Observations on Salt Water, and its application to the Generation of Steam."[1] By JOHN BARKER HUNTINGTON, Assoc. Inst. C.E.

FOR some time after the introduction of the use of steam as a propelling power, all inquiries into the laws regulating the properties of that agent, were confined to the consideration of steam from fresh water, such water being considered practically pure, when derived from rivers, or from springs issuing from the land; for though all fresh waters were found to be of a greater, or less number of degrees of hardness, due to the mineral compounds mingled with them, yet this hardness was not sufficient to disturb, in a sensible degree, the results of the investigation; therefore, the rules deduced and hitherto acted upon, have been confidently adopted by all manufacturers of steam machinery, when employed for land purposes. In course of time, the application of steam-propelling power to sea-going vessels followed; and, as a necessary consequence, salt water, instead of fresh water, became the agent for generating steam. But by this change of agents a serious disturbance of the laws hitherto prevailing took place, for sea water was found to contain such an excess of mineral compounds, held in solution, that new observations had to be made, in order to estimate correctly the amount and effect of the disturbance. The principal effect observed was, that salt water required a greater amount of heat to generate steam, than fresh, or land water. A correction of the proportions of the parts of marine boilers would easily overcome this objection; but this was the least of the difficulties resulting from the change. From time to time there occurred numerous accidents, sometimes attended by serious calamities, resulting chiefly from the use of salt water in steam boilers; and, even when the voyage was pros-

[1] This paper is only printed in abstract, the original communication being composed, in a great degree, of tabular statements.

perously achieved, a great waste of fuel was observed, for the amount of work performed did not bear a just comparison with the means used to produce it. These losses were perceived to arise, generally, from the incrustation of the salt on the bottom and on the sides of the boiler. The water in the boiler being converted into steam, and passing thence to the cylinders, the salt is left behind, not being convertible into vapour, and is slowly deposited, during continued ebullition; first, that part of it consisting of the sulphate and carbonate of lime, and then, after the greatest quantity of salt, which water can hold in solution, has been introduced, the common and other salts are precipitated, because, thenceforward, all the salt contained in the water, supplied into the boiler by the feed-pumps, not being able to remain in solution, separates itself, and adheres to the shell and flues. This deposit ultimately causes such an interruption to the communication of heat from the fire, salt being a very imperfect medium for the transmission of heat, that a great waste of fuel is the consequence; moreover, the fire acting intensely and continuously on minute quantities of water, enclosed among the crystals of salt adjacent to the flues, not unfrequently raises vapour of an extremely high pressure, ending in an explosion. The action of the fire, also, upon the flue-plates, becomes another source of risk and expense, because the heat having no longer a free passage to the water, but being intercepted by the incrustation of salt, gradually eats the metal away, and softens the plates, till the seams so weakened, being strained by the pressure of the steam from within, yield at last, and a fissure ensues. The use of copper, instead of iron, for the metal of the flues, is found to render them less liable to the action and incrustation of salt water, but it augments the first cost of the boiler, and is otherwise objectionable.

There have been many ingenious contrivances, for preventing these otherwise certain results. The general guiding principle of them all has been, to withdraw a certain quantity of brine from the bottom of the boiler, before the maximum density is reached. A cock, connected to a pipe communicating to the outside of the vessel, is turned on, when the density of the brine is considered to have progressed far enough; the internal pressure of the steam then forces out a large body of water, more, or less charged with a strong solution of salt: this is

replaced by the action of the feed-pump, by a quantity of sea water, containing the practical minimum of salt in solution, thereby rendering the whole body of water in the boiler of a less density. According to the capacity of the boiler, and the work performed by it, this operation requires to be repeated, at intervals varying from two to eight hours, and to this point the attention of the working engineer must be directed, as not only is the economy of the production of the steam power, intimately connected with a proper regard to the saltness of the water, but the security of the vessel is remotely contingent upon his care in this respect. Besides the above method of blowing out the water, brine-pumps have been introduced for the same purpose, whose constant action, by continually withdrawing a small quantity of a highly-saturated water, which is, at the same time, replaced by the water of ordinary density from the feed-pump, keeps the solution in the boiler at the constant degree of density, determined upon by the engineer as best suited to economical working. This method also relieves, in a great measure, the risk of too much reliance being placed on the discretion, or watchfulness, of the working engineer. As the use of sea water necessarily introduces the salt it contains, further attempts have been made to diminish the supply of this obstructive mineral, by mixing with it the condensed water from the engines, which contains little, or no saline mixture. This diminished solution is introduced into the boiler by the feed-pump at an elevated temperature, increased by the employment of "calefactors," through which the water passes on its way, absorbing heat from the discharged brine, and thereby still further advancing the economy of fuel. There are several modifications of these methods, which it is not necessary to describe, as their adaptation generally points to the same object, namely, to reduce to a minimum the increase of saline density in the boiler.

When a boiler is supplied to the best advantage by these contrivances, another point becomes deserving of consideration. Besides the waste of heat, and the danger arising from incrustation, in proportion as the water becomes more salt, or dense, the greater is the degree of heat necessary to produce vapour; for, if ordinary sea water boils at 213° Fahrenheit, water fully saturated with salt does not boil at a less temperature than

228°. It is, therefore, important to fix upon such a limit to the degree of saltness, as not to expend too great a quantity of fuel in the generation of steam; and this limit should be sufficiently extended, to avoid the necessity of blowing out the salt water of the boiler too often, because every operation of this kind is attended by a serious loss of heat, when the boiler is recharged by feed-water of moderate temperature.

In order that the engineer may ascertain, what quantity of salt the water of the boiler contains, there have been many suggestions and contrivances. The simplest and most favoured of these is the employment of the hydrometer, converted for this purpose into a salinometer, by a simple alteration of the graduations of the stem. It may be made of metal, or glass. Its ordinary construction consists of a hollow ball, to which a slender straight stem is attached on one side, and opposite to it a weight, sufficiently heavy to keep the stem in a perpendicular position above the ball, when immersed in a fluid. At the top of the stem, the mark zero indicates the point to which the instrument will sink, when immersed in pure rain-water. When placed in a denser fluid the stem rises, and the weight of the bulk of that part of the stem so projected, records, accurately, the excess of weight of the same bulk of the fluid above that of water, which is represented by the whole weight of the instrument. When the density of water is represented by 1, the hydrometer is usually graduated, so that 360° are equal to an increase of 1 in density, or each division corresponds to 1-360th increase of density, all the divisions being nearly equally apart. If the specific gravity of a fluid, not denoted by the foregoing scale, be required, it is usual to represent that of water by 1000 (the weight of one cubic foot in ounces), and the divisions are so graduated, that a fluid of twice the density of water is denoted by the mark 2000, and so on, in proportion, for any other density. All saline solutions increase in density in the exact proportion of the per centage, by weight, of salt dissolved; therefore, if the ordinary density of sea water, which is 1027 specific gravity, or 10 on the hydrometer, be taken as an unit, to form a new scale for a marine salinometer, then a series of graduations, corresponding to proportional increments of saline density, can be easily marked on the stem, for this special purpose. The most usual method is to insert a graduated slip of paper, when the stem is

made of glass tube, and to adjust it properly before the tube is hermetically sealed at the top. On most salinometers $3\frac{5}{16}$ is the extreme graduation, as it appears, hitherto, to be practically determined, that the water in the boiler should not exceed about three times the density of sea-water. To ascertain, by the hydrometer, the density of the water in the boiler, the engineer withdraws, by a cock conveniently placed, a small quantity into a deep vessel, at least equal to the length of the instrument. As this water comes out at a high temperature, it is necessary to let it cool down considerably before the instrument can be used, as the scale is generally constructed for the bulk of fluids varying in temperature from 50° to 70° of Fahrenheit. When sufficiently cooled, the instrument is carefully introduced into the fluid, and the graduation corresponding to the surface of the water is observed, which indicates, approximately, the density of the water in the boiler at the time of drawing it off. By a few observations of this kind, during a voyage, the engineer can judge of the state of his boiler at any given period, and by continued practice, he is enabled to foresee, when it will be necessary to blow off, or to work his brine-pumps, &c. In the absence of a thermometer, great caution must be exercised in deciding whether the water be cool enough for testing. If a thin tin vessel be used, it will begin to feel cool to the hand about 75° Fahrenheit, and at 65° is sensibly cool. Some hydrometers are constructed to be used at a temperature of 200°, immediately on the water being withdrawn, which is a great advantage. A thermometer, however, should, if possible, be employed upon all occasions, because a very small variation of temperature affects the density; for if the expansion of the fluid be considered uniform, which it is not, about 3° make a difference of 1-1000th of specific gravity, or 36-100ths of the hydrometer degree, or 36-1000ths of the density of sea-water.

With the exception of a brief mention in Tredgold's Treatise "On the Steam-Engine,"[1] the subject of incrustation in boilers does not appear to have elicited much public attention, before the year 1830, from which time to 1838 great improvements were made to avoid, or to remedy its effects. Besides mechanical con-

[1] *Vide* Tredgold "On the Steam-Engine," page 61. London, 1827.

structions of boilers, it was suggested, about that time, to coat the flues and shell, with substances which would resist the action of the affinity of the salt for the metal, and alkalies were proposed to soften the deposited crust. Messrs. Maudslay and Field had also tried experiments to ascertain the state of the brine, the particulars of which are recorded in Mr. Dinnen's appendix to "Tredgold on the Steam-Engine."[1] This is the first published account of the relative temperatures of brine and steam since Watt's experiments in 1774. The sea-water was kept boiling under a pressure of $2\frac{1}{2}$ lbs. per square inch, and the density of the brine gradually increased to saturation. The table given does not quite agree with more modern experiments: it is stated, however, that a thermometer is a practical register of the density of the brine, but as this was limited to one pressure only, of $2\frac{1}{2}$ lbs., it remains to be proved, whether the same scale can be applied to any other pressure, high or low. The argument is that such is the case, because muriate of soda, unlike other salts, is very little more taken up in solution at a high temperature than at a low one; and, therefore, the quantity remaining constant, the heat in the salt would increase uniformly with that of the steam. Moreover, it was inferred, that the boiling point of any brine drawn from the boiler, being observed by a common thermometer, the density could be ascertained without difficulty, it being assumed to be proportional to the increase of temperature above that of pure water. How far this supposition agrees with recent experiments will be seen hereafter.

Dr. Lardner appears to have devoted his attention to the subject at this time. He states, in a positive manner, that the temperature of the water, due to a given pressure of steam, varies considerably with the strength of the brine, increasing with concentration; he suggests, therefore, a comparison of the steam gauge with a thermometer immersed in the water of the boiler, and graduated, not in degrees of heat, but according to a scale denoting the amount of saltness. Instead of employing a thermometer, to which there are stated to be objections, he considers that the difference of pressures, indicated by salt water and by fresh water of the same temperature, would be an index

---

[1] *Vide* Appendix I., page 1, to Tredgold "On the Steam-Engine." Edited by W. S. B. Woolhouse. London, 1838.

of the saltness. To effect this, he recommended that a small vessel, containing distilled water, should be immersed in the brine, and a steam pipe be conducted thence to one side of a steam gauge, while a pipe from the steam chamber of the boiler should be conducted to the other side of the same gauge, so that a column of mercury raised by the difference of pressures from the steam of the two fluids, of different densities, would indicate, from hour to hour, the varying degrees of saltness. This scheme of Dr. Lardner's will not be found to agree with experiments.

In 1839, Mr. Seaward first introduced his salt-gauge, on board the Russian steam-ship "Nicolai," and in the course of the year published his invention, accompanied by a table, according to which it was regulated. A glass tube, of moderate diameter, communicates at the top with the steam chamber, and at the bottom with the water of the boiler, so that the level of the water is clearly seen. Two or three hollow glass balls, of different weights and colours, and of such specific gravity that they sink in common sea-water, are inserted in this tube. As concentration proceeds the lightest ball rises, and indicates that the limit of density is approaching; the second ball rises when that limit is reached, and when the concentration becomes practically excessive the third rises, and warns the engineer at once to reduce the density of the water. The table given varies from Messrs. Maudslay's at the higher parts of the scale, showing the necessity of a more accurate determination of the progression, to put the true construction of a salinometer beyond doubt. The simplicity of the above instrument is, however, commendable, as it is not liable to the risk of breakage, nor to the uncertain manipulation of the delicate hydrometer and thermometer; moreover, it answers two purposes at the same time.

But little seems to have been added to the stock of knowledge on this subject till 1845, when Dr. Ritterbandt introduced his method of preventing incrustation, by means of the muriate of ammonia, the particulars of which have become well known to the public, through the discussion on a paper by Mr. West, read before the Institution of Civil Engineers, in 1846.[1] In this same year (1845) Mr. Watteen proposed several methods, consisting of

[1] *Vide* Minutes of Proceedings Inst. C.E., Vol. V. page 182.

chemical mixtures, and gave recipes for the proportions of his mixtures, adapted to different powers of boilers and qualities of water. In 1848, saw-dust and charcoal were recommended by Mr. Seaton, to prevent incrustation in boilers. In 1850, Mr. How proposed a salinometer, which consisted of a vertical cylinder, connected to the top and bottom strata of water, with a floating hydrometer always in action. The apparatus was also provided with an overflow, waste-pipe, and thermometer, which was necessary to correct the graduations of the hydrometer. In the same year Mr. Spray proposed a simple instrument, which was merely a thermometer, on the bulb of which the water was allowed to act freely, the graduations indicating the degree of density. The former instrument is necessarily complicated, and except that it is a fixture, has no advantage over the common method; and the latter does not provide a comparison with the varying temperature of the steam generated, and can only be graduated for a given pressure.

In 1844, Mr. Scott Russell skilfully adapted a well-known hydrostatic principle to ascertain the density. If a fluid be contained in an inverted syphon, and stand at a given level, and another fluid of different density be introduced into one of the legs, the first fluid will rise in the other leg till its height balances the weight of the second fluid, and consequently the difference between the two columns indicates the difference in the specific gravities of the two fluids. To apply this principle, an instrument is attached to the boiler, having two glass water-gauges, sufficiently long to embrace the practical range of evaporation, say, from 6 inches to 10 inches at least. At the bottom of each gauge is a stop-cock, to connect the gauges with a waste-pipe, with the bottom brine of the boiler, or with each other. The top of each gauge is connected with the feed-water, and also with the steam chamber, but separately. When the brine is made to stand at equal heights in both gauges, a certain column of feed-water is introduced upon the brine in one gauge, when the brine rises in the other. The difference of level of the two columns is registered, in degrees of saltness, on a scale between the gauges, which may be indifferently used for the same purpose. How far this instrument, true in theory, may succeed in practice, remains to be proved; but there seems to be a practical difficulty in preventing the columns

of fluids from mingling, so as to insure any degree of nicety of observation, though it may afford a very ready approximate measure. There are, doubtless, many other unrecorded attempts at indicating the saltness of brine, which have not come under the notice of the Author; but those already mentioned appear to comprehend the principal varieties of means, that may be employed for that object.

The foregoing brief sketch of the ordinary knowledge on this subject is all that is necessary to demonstrate how imperfect are the data at present, though here and there glimmerings of truth may be observed, but unsupported by experiments and deductions of a conclusive nature. The object of this essay being to determine the saltness of brine, rather than to give a description of the mechanical construction of boilers and their apparatus, all the inquiries are directed solely with a view of determining the properties of salt water, and of deducing practical rules from the results. At present, there is little beyond rude practical knowledge, to determine the economical use of fuel, or the cost of power; and though in skilful hands, with a sound judgment, a vessel may be, and is securely and properly worked, yet if science can point out a surer method than is afforded by the instruments already described, it appears to be a duty to discover it, so as to relieve the engineer of part of his responsibility, by adding greater security to his calculations, in rendering certain what he now only arrives at by approximation. The principle on which a good salinometer should depend, when properly constructed, is to provide the means of determining the quantity of salt contained in water at any temperature. Recourse must be had to experiments to know the constituent parts of salt water, the relation of the weight of salt to the specific gravity of a solution, the boiling points of solutions, their state when under pressure, and the law of their expansion, from which data general principles will be clearly established for future guidance.

In the first place the analysis of sea-water should be known. Its specific gravity varies from 1026 to 1031; but in inland seas it is often more dense; the specific gravity of that from the Dead Sea is 1211. 1000 parts of sea-water contain from 22 to 28 parts of muriate of soda, and from 8 to 13 parts of other salts, which are chiefly soluble at high temperatures, except the

sulphate and carbonate of lime, which average together 4-10ths of a part in every 1000 parts of sea-water.

Common salt contains from 94 to 96 parts of muriate of soda, and from 6 to 4 parts of other salts, in 100 parts of dry salt.

Sea salt contains from 72 to 77 parts of muriate of soda, and from 18 to 13 parts of other salts, in 100 parts of dry salt.

In the experiments from which the results of this Paper are derived, a saturated solution of common salt had the specific gravity of 1213, or 77° of the hydrometer, and 100 parts of pure water dissolved very nearly 40 parts of salt at 60°; whereas, a saturated solution of sea salt has the specific gravity 1236, or 85° of the hydrometer, for the same weight (40 parts), dissolved by 100 parts of water; but these are necessarily variable, because the constituent parts of sea salt vary, the greater the proportion of muriate of soda, the less being the specific gravity for the same weight of salt in the solution.

When salt water is heated, the increase of temperature of the brine, above that of pure water, is entirely due to the salt, for the steam arising from both waters exhibits identical temperature, under similar pressures; hence the loss arising from this source is measured, not by the density of the solution, but by the salt dissolved in a constant weight of water; for the water which is evaporated takes away no more heat at one density, than at another, therefore, the loss must be due to the salt left behind. The capacity for heat, exhibited by brine, is greater than that of pure water, inasmuch as at a density of 39° of the hydrometer, 110 tons of coals are required to perform the duty of 100 tons with pure water.

In making experiments, the thermometers require much attention; first, in their construction, then in the several corrections for the barometer, the expansions of glass and mercury rendering them objectionable for testing the saltness, even if the mercury do not clog in the tube.

In the periodical blowing off of boilers there are, at least, three losses to be calculated: 1st, the loss by capacity for heat; 2ndly, by the injection of the feed-water; and, 3rdly, by the blowing out and restoring the deficiency by feed-water.

From calculations made upon two boilers of very different dimensions, with feed-water and steam of different temperatures,

it would appear, that to blow out one-sixth, at intervals varying from six hours to ten hours, working from a density of 30° to 35°, is the most economical, as the quantity of fuel required becomes greater on both sides of these limits.

The following are the general results arrived at by the experiments:—

1. The per centage of salt in a solution is in direct proportion to its density.

2. The time required to attain a given degree of concentration is directly as the departure from concentration of the original density, the capacity of the boiler, and the relative volume of steam; and, inversely, as the feed-water density, the capacity of the cylinder, and the velocity of motion.

3. As regards time, it is preferable to employ low pressures, as it takes longer to arrive at a given concentration, as the pressure is lower.

4. For equal weights of salts, dissolved in equal weights of water, the more heterogeneous the salts, the greater the density they exhibit in solution.

5. The excess of the boiling point of a solution, above that of pure water, is not proportional to its density, but to the quantity of salt dissolved by a constant weight of water.

6. The boiling point is affected by atmospheric changes, as indicated by the pressure of the steam, which balances the barometric column.

7. The capacity for heat, of brine, is directly proportioned to the salt dissolved by a constant weight of water.

8. The depression of the freezing point, of brine, below 32° Fahrenheit, is similarly proportioned.

9. The excess of temperature of the water of any solution, above that of the steam generated from it, whether below, or above atmospheric pressure, is constant for any solution, whatever be the pressure and temperature of the steam: this excess is in direct proportion to the quantity of salt dissolved by a constant weight of water.

10. The expansion of any solution, in excess of the expansion of pure water, is in direct proportion to the salt dissolved by a constant weight of water.

11. Boilers should be small, as regards water space, and the feed-water be as hot as possible, to save fuel.

12. The density of the feed-water should be kept as low as possible.

13. In constructing hydrometers, the quantity of salt left behind, for every 100 parts of water evaporated, should be registered, as upon this quantity must depend all calculations of effect in fuel.

14. Hydrometer-makers should not only engrave the temperature for which the instrument is fitted, and the scale of saltness, but also the specific gravity of the sea water, on which the scale was formed, and the proportion the muriate of soda bears in 100 parts of dry sea salt, in order to be able to make the necessary corrections for the varying saltness of the sea.

15. In order that sulphate and carbonate of lime should not be deposited, the degree of saltness should not exceed 25 parts for every 100 parts of water, or 60° of the hydrometer.

[Mr. Huntington

Mr. Huntington explained that as it had been necessary to omit the Tables in the reading of the Paper, he wished to say that they showed :—

1. Results of Messrs. Maudslay and Field's experiments as to the relative temperatures of the brine and steam. 2. Results of Mr. Seaward's ditto ditto. 3. Analyses of different sea waters by Dr. Ure, Dr. Lardner, Dr. Murray, Schweitzer, and Laurens, and of common salt by Dr. Henry. 4. Experiments on the densities of different solutions. 5. Chemical analysis of salt. 6. Results of Gay-Lussac's experiments, to show that when the temperature of the water is raised, a greater quantity of common salt is required to saturate the solution. 7. Value of multiplier for pressures varying from 1 lb. to 20 lbs. per square inch above the atmosphere, in rule for determining the time required to acquire any concentration. 8. Results of Tredgold's experiments on the boiling points of solutions. 9. Results of experiments on the boiling points of solutions. 10. Sir G. Shuckburgh's barometric boiling points. 11. Dalton's pressures of steam near the atmospheric boiling point. 12. Correction of boiling points. 13. Capacities for heat of common salt, as determined by M. Gadolin. 14. Freezing points of different solutions, as determined by Mr. Griffith. 15. Capacity for heat of saline solutions. 16. Results of Watt's experiments with steam of a saturated solution. 17. Differences between the temperatures of the water and steam at several densities. 18. Temperatures of steam, at different pressures. 19 and 20. Showing the fuel required for a given capacity of boiler and pressure of steam. 21. Results of De Luc's experiments as to expansion of saturated solution of salt and of pure water. 22. Results of Dalton's and Gilpin's experiments on the expansion of pure water. 23. Results of experiments on the expansion of a saturated solution of salt. 24. Showing the loss of specific gravity by the expansion of pure and salt water. 25. For calculating corrections for the expansion of water and salt. 26. Showing graduations for salinometer scales. 27. Ditto corrections for the water. 28. Ditto for the salt and temperature.

Dr. Ritterbandt said, it remained with the engineers to agree upon an instrument to determine the saltness of water. He had found that, in many ports of the United Kingdom, the instruments used for that purpose were different. If correct

results were to be arrived at, it was absolutely necessary that one and the same description of instrument should be adopted, so as to induce uniformity in the observations. He considered that it would be useful to have an indicator of brine saturation, out of the reach of the engineer; it would be safer in that position, and would undoubtedly lead to economy of fuel. As regarded the density of the water, supposing it to contain 3·5 per cent. of salt, if the engineer permitted eight times that amount, it would equal 28 per cent., which was too dense to be economical. Water would absorb a quantity of salt, which would raise its specific gravity to three times this amount, but at that degree it would be dangerous. There was very little salt really precipitated in the boilers; it was chiefly an incrustation, resembling salt somewhat in appearance, and consisting of carbonates of lime and magnesia, with small portions of sulphate of lime and of some common salt, if the density of the brine had been allowed to rise to its point of saturation.

Some time since he had used muriate of ammonia for preventing incrustation in marine and other boilers. It succeeded excellently with fresh water containing carbonate of lime. With salt water it did not absolutely prevent all incrustation, but it retarded its progress, and therefore the boilers did not require to be blown out so frequently. By the use of muriate of ammonia no great amount of incrustation was formed on the voyage, and on arrival in port the boiler was easily cleaned out.

In 1847, the Admiralty ordered some experiments to be tried at Portsmouth, to test the merits of the application. The practice had been to blow off when the hydrometer indicated 18° and 19°. By the use of muriate of ammonia, it was found that there was no incrustation, or deposit, even when the water had arrived at 60° hydrometer, or above three times the ordinary point of blowing off. In fact, the necessity of blowing off at 19° or 20° did not arise from the accumulation of salt in the water at this density, but from the deposition of the carbonates of lime and magnesia, held in solution by the free carbonic acid, which was expelled when arriving at this point, and this, the addition of muriate of ammonia completely prevented, so that the concentration of the water could be carried up to the point of saturation by the salt, but could not be carried beyond it, for then salt itself was deposited.

May 3, 1853.

JAMES MEADOWS RENDEL, President, in the Chair.

The following Candidates were balloted for and duly elected:—Herbert Francis Mackworth, as a Member; James Forbes, James Needham Gildea, Henry Palfrey Stephenson, and Lieutenant Henry Whatley Tyler, R.E., as Associates.

No. 895. "Description of the Chesil Bank, with remarks upon its origin, the causes which have contributed to its formation, and upon the movement of Shingle generally."[1] By JOHN COODE, M. Inst. C.E.

THERE are few subjects of greater professional interest, than the accumulation and travel of shingle, since the very existence of many harbours depends, in a great degree, upon a correct understanding and judicious application of the laws which govern its movement; and without a knowledge of these, it is impossible to devise such measures as may with confidence be adopted, either to assist its progress, direct its course, or to remove accumulations that may have taken place. Such being the case, it is somewhat surprising, that conflicting opinions should be found to exist, and that there should be an unusual absence of well-ascertained facts bearing upon the subject.

The Chesil Bank is one of the most remarkable features of the south coast of England. It is perhaps the most extraordinary, and at the same time the most extensive, accumulation of shingle, to be met with in this country; there is reason to hope, therefore, that a description of it may not be devoid of interest, to the Members of this Institution.

It is proposed to give, in the first place, a description of the Bank as it now stands, with a notice of its past condition, according to the best authorities; and secondly, to point out the sources from which the shingle has been derived, with some

[1] The discussion upon this Paper was extended over a portion of two evenings, but an abstract of the whole is given consecutively.

remarks upon the causes contributing to the formation of the Bank, and the conditions and circumstances which affect the movement of shingle generally.

It should further be premised that, with the exception of Fig. 1, which is compiled from authentic sources, the plans, sections, &c., on Plate 2, have been constructed from a great number of careful observations made by, and under the directions of the Author, for the special purpose of ascertaining and recording the facts connected with this great work of nature in its present state.

Fig. 1 is a general chart of the West Bay, showing the geological features of the coast line.

Fig. 2. Plan and longitudinal section of the Chesil Bank, showing "The Fleet," Portland, &c.

Fig. 3. Transverse sections of the Bank, at three points, as marked by the letters A F C on the plan and longitudinal section, Fig. 2. These sections represent its ordinary summer condition, and extend to 600 feet, seaward, from low-water mark.

Fig. 4. A section of the west side of the Bank, near "Chesil," showing the profile of the Bank after the gale of 27th December, 1852, and its close correspondence with a true parabola.

Fig. 5, is a plan, with contour lines, of a gully or "can," caused by the water passing through the Bank during heavy south-west gales.

Fig. 6, shows one of the peculiar boats, called "lerrets," used by the fishermen on the Chesil Bank.

The Chesil Bank is a vast mound of shingle, in the form of a narrow isthmus, lying upon the western seaboard of Dorsetshire, between Abbotsbury and Portland; its general direction, or bearing is south-east, and its length is 10¾ miles.

Commencing at Abbotsbury Castle (to the westward of which the shingle slopes down from the low cliffs, as in the case of an ordinary beach) the Bank skirts along the margin of the meadows, for half a mile, when it meets "The Fleet" or "Backwater," a shallow estuary varying from a quarter to half a mile in width; it then runs parallel to the general line of the main land as far as Wyke, a distance of eight miles; from this point, the Bank takes a more southerly direction, until it joins the Peninsula, or what is more commonly called the Island, of

Portland, when it again assumes the character of an ordinary beach.

South of Wyke, the Chesil Bank acts as a natural breakwater to the anchorage of "Portland Roads," in the East Bay, sheltering it against westerly and south-westerly gales; the whole of the western face of the Bank is washed by the waters of the "West Bay," which extends from Start Point to Portland.

The average width of the Bank at the base, or level of low water of ordinary spring tides, is 170 yards near Abbotsbury, and 200 yards at Portland.

The height of the Bank increases from north-west to south-east, but the inclination of the crest, or highest part, is not uniform throughout; from Abbotsbury to Wyke, the rise is very slight, and remarkably regular, being only 5 feet in 8 miles, or at the rate of 1 in 8,450; from Wyke to Chesil the rise is 15 feet, the rate of inclination being 1 in 880, and the distance 2½ miles. At Chesil, the shingle strikes the land, with which it turns rapidly to the southward, and the height of the Bank immediately begins to diminish; at one-third of a mile south of the highest point, the shingle once more rests against the cliff, and at a point about 300 yards distant it ceases altogether.

The form of the Bank, in its transverse section, is of considerable interest. Equalizing the minor inequalities which occur from time to time, there exists one general slope from the summit of the Bank, to a given depth below low water; the rate of this slope, or inclination is 1 in 7 at Abbotsbury, and 1 in 5½ at Portland; the depth of water at which this terminates, is 3½ fathoms in the former case, and 4½ fathoms in the latter. Again, the inclination is in every case less for the next two fathoms in depth, being 1 in 11 at Abbotsbury, and 1 in 8 at Portland. Further out, or seaward, there is a still flatter slope, about 1 in 30, to the point where the shingle terminates altogether, which is 6 fathoms at Abbotsbury, 7 fathoms at Fleet, and 8 fathoms at Portland;[1] beyond this there is fine sand and no shingle whatever.

After trials with a boring-bar, driven through the Bank at several points, down to high water in some cases, and nearly to

---

[1] It may be well to state, that sections were taken, and frequent observations were made, at eight different points along the bank. The three sections Fig. 3, Plate 2, will be sufficient to elucidate the remarks in this Paper.

the level of low water in others, the existence of clay, which is generally supposed to form the nucleus, has not been discovered, in a single instance, either in the body of the Bank, or on the west side. On the east side, however, at the level of from 3 to 4 feet above low water spring tides, a stiff silty clay was met with. With this exception, nothing but shingle was found at each of the points tested; and this, on reaching to a depth of about 10 or 15 feet below the surface, was usually mixed with a small quantity of sand, the proportion of the latter increasing, the deeper the bar was driven, until it became so compact, that it required a power of many tons to withdraw a bar of $1\frac{1}{4}$ inch diameter, from a depth of 18 or 20 feet. As a further proof of the solidity of the mass, it may here be noticed, that the water never percolates from the West Bay into the East Bay, except in the heaviest gales from the south-west, notwithstanding that ordinary spring tides, in moderate weather, rise 2 feet 3 inches higher and fall out 2 feet 9 inches lower on the west side, than upon the east, the range being 12 feet 6 inches and 7 feet 6 inches respectively. The greatest observed difference in the level of the tidal waters in the two bays, at the same period of time, occurs about $1\frac{1}{2}$ hour before high water, when the level, on the west side of the Bank, is from 3 feet 9 inches to 4 feet higher, than on the east. It will be observed, that the difference of level due to the rise of the tides only, has here been spoken of; but the crest of the waves, breaking on the west side, will very frequently run up the slope of the Bank, as much as 8 or 10 feet vertically, above the mean level of the water, so that a momentary difference of 10 or 12 feet is not an uncommon occurrence.

The same rule obtains, upon the Chesil Bank, as upon all other beaches, in respect of the largest shingle being found at the end farthest from the point, or quarter, from which the heaviest seas proceed, or what—when speaking of the wind—would be called "to leeward." This is so evident, in the case now under consideration, that it is frequently said in the locality, "If you land a Portland fisherman upon the Bank, in the darkest night, he will know his position by the size of the pebbles." That this may be done, within certain limits, by those well acquainted with the Bank there can be no question. The only safe criterion, however, lies in judging by the relative

sizes of the small shingle, found immediately upon the top, or crest, as the gradation in size, at that level, is very regular, and is not subject to variation, as is the case at the lower levels.

The shingle of the Chesil Bank is composed, chiefly, of chalk flints, with a small proportion of pebbles from the red sandstone, some of these being of a dull-red colour, others of a brown, or dull yellow, with occasional red marks resembling blood-spots. A peculiar kind of jasper pebble, with flesh-coloured red predominating, is not very uncommon: these have sometimes been mistaken for Devonshire limestones, to which many of them bear a great resemblance; they do not, however, contain any calcareous matter, as there is not the slightest effervescence on the application of muriatic acid. There are also, occasionally, pebbles which are decidedly porphyritic, both green and red; they are comparatively rare, but nevertheless are found in sufficient numbers to prove, that their presence is due to something more than accidental causes.

The earliest notice of the past condition of the Bank appears to be Leland's description of "The Fleet" and "Chesil Bank," written A.D. 1546, (Itin. Vol. III., p. 66), which is as follows:—

> "This arm (viz., that runneth up by the right hand of Weymouth Haven, to Portland Passage) goith up from the strait of the Trajectus, and is of a good bredth, and se like goith up to Abbates-Byri about a vij miles of, where is a little fresh water resorting to the se. A litle above Abbates-Byri is the head, or point of the Chisil, lying north-weste, that from thens streatch up 7 miles, as a maine narrow banke by a right line on to south-est, and ther buttith on Portland, scant a quarter of a mile above the new Castell, in Portland. The nature of this bank of Chisil is such, that as often as the wind bloweth strene, at south-est, so often the se betith it, and losith the bank, and breaketh it thorough it. So that if this might continually blow there, this bank should sone be beten away, and the se fully enter, and devide Portland making it an isle, as surely in tymes past it hath beene, as far as I can by any conjecture gather. But as much as the south-est wind dooth bete, and breke off this Chisille bank, so much doth the north-west wynd socor, strengith and augmentith it. Portland hath been of auncient tyme, by

al likelihod, environid with the se, and yet berith the name of an isle."

Next in order of date is Camden, in whose "Brittania," edition of 1590, translated by Gibson, is the following passage:—

> "From hence, the shore widening very much, runs out into the sea, where a heap of sands thrown up, called Chesil, with a narrow sea that runs between it and the shore, continues for nine miles together; which when the south wind rises, gives, and commonly cleaves asunder; but the north wind, on the contrary, binds and consolidates it."

Smeaton, who visited Portland in the year 1756, in order to examine the quarries, with a view to the employment of the stone from that place, in the Edystone Lighthouse, thus notices the Chesil Bank, in his admirable work on that structure.[1] He says (pp. 63 and 64), "But what struck me most with wonder and amazement was the Portland Beach, which I could not enter the island, in crossing the salt-water creek from Weymouth, without remarking; and which perhaps renders it impossible to decide whether Portland is really and properly an Island or not."

He adds in a note, "If an island, with Dr. Johnson, is defined to be a tract of land surrounded with water, then this certainly is not an island; but if it be defined to be a tract of land, whose component strata are altogether detached from the main land, in this sense it may justly be denominated an island."

He then describes the salt-water creek running behind it, and imagines that the Bank could not have had its origin at a very remote period, because the irregularities in the land adjoining the salt-water creek were very distinct. He seems to think that the Bank was formed somewhat suddenly, "for," says he, "had a quantity of pebbles been washed up from the sea, and brought to the shore gradually, there does not appear to be any reason why the action that brought them thus far, should drop them short of the shore, and not heap them upon it; in which case, no salt-water creek would have been formed; for then the little

---

[1] *Vide* 'A Narrative of the Building and a Description of the Construction of the Edystone Lighthouse with Stone,' &c. By John Smeaton. 2nd edition. Folio. London, 1793.

irregular bays in the shore would have been first filled up, and the whole mass brought forward in the same kind of fair curve, as we now find it; but from whence such a mass of pebbles should come, as very soon to form so great a barricade as to shut out the sea, is a problem not seeming to admit of an easy solution."

Hutchins says, at p. 587 of his work on the "History and Antiquities of Dorset," published in 1774:—"The Beach, or Chesil, called also Steepstone Beach, is very remarkable, and derives its name from Ceoyl, the Saxon name for gravel. It is a prodigious heap, or body of pebbles thrown up by the sea. The beach is very large and high at Chesilton, and the pebbles generally of the size of a pullet's egg, and many much larger, but they lessen gradually to the west, and at Swyre are no bigger than pease, or gravel."

In these records no dimensions of height, or width, are given, but the conclusion to be drawn from them is, that the shingle has of late years somewhat increased in quantity, as it does not appear that the Bank has been broken through, at any point since the commencement of the present century.

The origin, or source from which the shingle is derived, and the causes which have contributed to the formation of the Bank, next claim attention.

Starting upon an examination of the geological character of the coast line, and the beaches, from Portland Bill, at the eastern extremity of the bay, and following the line of shore westward to Start Point, it will be found, that there is no shingle whatever on the west side of Portland, until after passing Blacknore Point; midway between this point and Chesil, there is an accumulation, consisting entirely of oolitic pebbles, some from the *dêbris* of the strata lying above, and others from the rubble and quarry waste, thrown over the cliff, immediately to the west of Blacknore. At 250 yards south of the village of Chesil, the shingle of the Bank is first met with. Passing on to the main land at the "Ferry Bridge," near Wyke, and pursuing a course along the shore of the Fleet, the "Kimmeridge Clay" comes first in order, and after this "Coral Rag," "Oxford Clay," "Cornbrash," and "Forest Marble," successively, up to Abbotsbury; then "Fuller's Earth" extending to Burton Cliffs, which are in the "Inferior Oolite," and from Eypes' Mouth, one mile west of

Bridport Harbour, "Marlstone" and "Lias" are found; these form the lowermost beds of the oolitic series, and extend to the westward of Lyme Regis. So far, at all events, there are no strata which would yield any materials, corresponding in character to the shingle on the Chesil Bank. Between Lyme and Axmouth, however, appears the first indication of chalk with numerous flints; the fall of this material is much accelerated by the wasting of the "Green Sand," upon which it rests; and in this way the cliffs between Lyme and Sidmouth have afforded a considerable supply of flints, the chief source being in the vicinity of Beer Head, which is well known as the westernmost chalk cliff on the English coast. Westward of Sidmouth comes the "New Red Sandstone" series, and at Budleigh Salterton, the beach is almost entirely composed of pebbles, of precisely the same kind as those previously described as of a dull uniform red, and also those which are marked with red spots, both of which are derived from the rocks in the immediate vicinity. Upon this beach are also found the jasper pebbles, already spoken of, which after some trouble, have been traced to Aylesbere Hill about six miles north, whence they have been transported by the River Otter; they are found at various points along the valley of that river, but not to any distance on either side of it. As to the porphyritic pebbles, it has been kindly suggested to the Author, by the Very Reverend W. D. Conybeare, Dean of Llandaff, that they may be *re*-derived from the Heavitree conglomerate among the lower deposits of the "New Red Sandstone," all the beds of which crop out on the coast between Beer and Torbay, at which place the "Devonian Rocks and Limestone" occur; these extend three miles beyond Slapton, and then join the "Chlorite Slate," of which material the Start Point, and the cliffs for about ten miles further west, are composed.

The result of this examination is then, that no rocks, or shingle, similar in character to the pebbles of the Chesil Bank, are found along the shore to the eastward of the village of Chesil; but that the several kinds may be traced in greater, or less quantities, upon the beaches along the whole of the intervening coast, as far as the chalk between Lyme and Sidmouth. At a very short distance to the westward of the latter place, the flints are no longer to be found; the sandstone pebbles, however,

continue down as far as Budleigh Salterton, which is the locality of rocks of the same character; the jasper pebbles also extend to this place, but not to any distance beyond, the beach at Exmouth being composed of sand.

Next comes the question—Are there, or have there been, sufficient causes in operation to transport the shingle to the Chesil Bank, from points so distant as these, and to deposit it, in the form of a high mound, when it arrives there? To prove that there are, will not, it is conceived, be difficult.

It is held by some persons, that the tidal currents are the chief agents at work in the transport of shingle, whilst the action of wind-waves is regarded as secondary; the opinion being, in short, that the waves merely lift the shingle, and place it in the most favourable condition for the tidal currents to act upon, and carry it along. This view appears to the Author to be altogether untenable. That the tidal currents may, and sometimes do, modify the extent and form of shingle accumulations, will hereafter be shown, but many facts may be adduced to prove that the onward progress is due to other causes.

The late Mr. H. R. Palmer, in a paper "On the Motions of Shingle Beaches"[1] gives three reasons, against the notion of the tidal currents being the principal cause of the forward movement of the shingle.

First he says, "If it were so, the direction of the motion of the pebbles would be determined by that of the currents; but while the direction of the currents will vary with the changes of the tides, we find that the direction of the pebbles may remain unaltered; and also that the motion of the pebbles is continued where no current exists."

He then remarks upon the low velocities of the currents, along the coast, under his observation, being insufficient to give motion to pebbles of all sizes; and states that "The motion of a current will not produce that order in which the pebbles are found to lie," here alluding to the order of sizes, when taken up and down the slope, or in a line drawn transversely to the general direction of the beach.

To these may be added the following reasons and facts:—

1st. The large shingle is always found "to leeward," which

[1] *Vide* Phil. Trans. Royal Soc. 1834, Part II., p. 567.

circumstance appears to have been entirely overlooked by Mr. Palmer: this, manifestly, cannot be the result of any tidal current: moreover, in the case of the Chesil Bank, it happens, that there is a marked change in respect of a more rapid increase of size in the shingle, from Wyke to Portland, and this change occurs precisely at the point, where the velocity of the tide-stream begins to slacken, the shingle becoming larger, and the strength of the stream decreasing, towards Chesil.

2nd. Much of the shingle is rough and irregular in form to the westward, but even the flints become smooth and rounded at the eastern end of the Bank; the current, of $1\frac{1}{2}$ to $1\frac{3}{4}$ knot per hour (which is the strongest tide-stream found within the bay, to the westward of Portland), and the comparatively short distance travelled, would certainly not cause an amount of attrition, sufficient to account for this change of form.

3rd. That in all cases the shingle terminates suddenly, at some particular level, or depth of water, and this depth varies with the degree of exposure and aspect of the shore, whilst the velocity of the tidal current remains practically the same, from Lyme to Wyke. The facts here stated, apply, it is true, more especially to the West Bay and to the Chesil Bank, but similar results have been found in a greater, or less degree, upon such other beaches as have come under the Author's observation.

Two remarkable instances may here be cited, of shingle travelling in opposition to the prevailing current of the tide. The first is the case of the beach between Blacknore and Chesil, previously noticed: this has travelled half a mile along the shore, towards the north, or into the bay, notwithstanding that the tide here sets to the southward, or out of the bay, for nine hours out of twelve; and further, that the outset runs three knots an hour at spring tides, whilst the in-going stream makes only one knot.

Again,—on the eastern face of the Chesil Bank itself, between the Ferry Bridge under Wyke and Portland Castle, the shingle immediately upon the shore of the roadstead, travels from south-east to north-west; whilst the stream of ebb tide and the water from "The Fleet" combined, run out (or to the south-east) for $9\frac{1}{4}$ hours; the flood, or north-west stream, running in at scarcely half the velocity for the remaining $2\frac{3}{4}$ hours only. This movement is the more remarkable, as it will thus be seen, that upon the east side the pebbles are carried

towards the north-west, or directly in opposition to the movement of the great body of shingle on the Bank.

Having shown that the progress of the shingle cannot be attributed to the action of the tidal currents, it now becomes desirable to take into consideration the effect of the wind-waves.

The prevalence of west and south-west winds, in this latitude, is well known; as is also the fact, that the greatest number of heavy gales are from about the same quarters. Such a statement, although incontrovertible, is somewhat indefinite; it will, therefore, be more satisfactory to refer to the best-recorded observations, and information upon the subject. This will be found in a "Report on the Working of Whewell's and Osler's Anemometers at Plymouth, for the years 1841-42-43," contained in the volume published by the British Association for the Advancement of Science for the year 1844.[1] The paper is very interesting, and the well-known scientific attainments of Sir William Snow Harris, by whom it is drawn up, give additional value to the results and views there stated. It is explained, that the results have no reference to "the *prevalence* or *frequency* of any particular wind in a given place, but its particular, or integral effect, that is to say, the comparative distance over which a particle of air would pass, during the time a certain wind blows;—and this may with a strong east wind of only one day, far exceed in effect the breezes of a gentle west wind of a week."

To give, as concisely as possible, the conclusions arrived at, it was found, by reducing the numbers registered by the instruments to two rectangular forces, whose intensity and directions are given, that according to Whewell's anemometer, the direction of the resultant was N.N.E., the wind being S.S.W., with a velocity of 3·8 miles per hour; whilst according to Osler's anemometer the results are,—direction E. 14° N., or E. by N. nearly; and the velocity 4·22 miles per hour. The mean velocities correspond pretty closely. To account for the difference in direction, it is mentioned, that Osler's instrument has left traces of the prevalent weak westerly and northerly winds,

---

[1] *Vide* Report of the Fourteenth Meeting of the British Association for the Advancement of Science, 8vo. p. 241. London, 1845.

which have not produced their full effect upon Whewell's instrument, especially as compared with the strong southerly and easterly winds. The instruments appear to have been wanting in strict agreement as to direction: thus much, however, is apparent, that the mean of the strongest winds is given by Whewell's anemometer. The want of sensitiveness of this instrument, renders its results the more valuable for this immediate purpose, inasmuch as it has registered only those winds which would create an amount of disturbance in the water, sufficient to affect the shingle. On the chart, Fig. 1, Plate 2, are given, both the line of direction, according to Professor Whewell's instrument, S.S.W. as before stated, and also a line S.W. $\frac{1}{2}$ W., which is a mean of the results by the two instruments; the last-named line will, it is thought by Sir William Snow Harris, be found correct, as representing the mean annual direction of the wind.

If then a S.S.W. line be traversed across the bay, it will be found to intersect Berry Head, and strike the coast line to the westward of Otterton Head, just at the very point, where the sea would take effect upon the sandstone pebbles, found upon Budleigh Salterton beach,—as also the jasper pebbles spoken of as brought down by the River Otter,—and carry them to the north-east. The line of S.W. $\frac{1}{2}$ W., drawn through the same point, would carry them to the eastward still more effectually. The "Devonian Rocks and Limestone," would be within the range of the S.S.W. line, drawn through Berry Head, and the wind from S.W. $\frac{1}{2}$ W. would, to this part of the coast, be "off shore;" now it is found, that no pebbles, deriving their origin from these rocks, or from the "Chlorite Slate," are to be found upon the Chesil Bank. As a proof that the ultimate movement of the shingle along this part of the coast is decidedly to the eastward, reference may be made to the circumstance, that at the period when flints were in general demand for gun-locks, and for producing light for domestic purposes, it was customary to send from Budleigh Salterton to Sidmouth, or Branscombe, to procure them, as none could be found upon the beach at the former place; this fact is simple, but conclusive. The Budleigh Salterton and Sidmouth pebbles may be traced eastward, from their respective localities, and will be found, in greater, or less quantities, upon the several beaches, up to the Chesil Bank,

where they find a resting-place, and at Chesil they cease altogether.

A line from S.W. ½ W., drawn through the "Start," would strike the land at a point near Burton Cliff, to the east of Bridport Harbour: it is worthy of notice, that although the general bearing of the coast is the same from Charmouth to this point, as it is further eastward, yet the shingle here begins to be thrown up, in much greater quantities, and of larger sizes; and it is further remarkable, that the depth of water into which the shingle extends, is found to increase suddenly at this point, as will be hereafter shown.

Proceeding on to Portland, drawing S.S.W. and S.W. ½ W. lines, along the western side of the island, it may be seen how,—with the wind from either of the above quarters,—the seas driving along the shore would arrest the further progress of the shingle. This is actually the case, and here it is compelled, by the direction of the shore, to sweep round and meet the waves, coming from the very same quarters, as those which originally gave it motion, in an easterly direction. This is a striking instance, of a vast body of shingle being stopped, by the action of purely natural causes,—and affords an example which may not be without its value to the profession.

The examples already given, with those of other beaches which might be adduced, all lead irresistibly to the conclusions, that the ultimate movement of shingle is always found to be in the same direction as, and never against, the heaviest seas; and that it is frequently in opposition to the prevailing, or strongest tidal current.

It now becomes necessary to offer some remarks upon the form of the Chesil Bank, the disposition of the shingle, and other peculiarities which have been already but slightly noticed.

The isolation of the Bank, separated as it is from the land, and running along as a vast mound for upwards of ten miles, is certainly one of its most peculiar features. Neither the small quantity of water discharged into "The Fleet" by the stream at Abbotsbury, nor the very slight flow of tide, will suffice to account for this; as this stream discharges only about eighty cubic feet per minute under ordinary circumstances, and the level of the water, at the north-west end of "The Fleet," does not vary more than one foot during the highest

spring-tides; at neaps, no change is perceptible. Moreover, the Bank has the same sectional form, in the meadows at Abbotsbury, as it has along "The Fleet," on the shore of the East Bay, and through the village of Chesil. This form appears to be due to the existence of a comparatively level bench of clay, (which has been found at several points, about the level of low-water, on the east side), together with a sudden drop, or increase of depth seaward, or towards the south-west. The unusual depth of water,—upwards of eight fathoms at a cable's length off,—allows the heaviest seas to fall in on the Bank, with great violence, throwing the shingle up to an unusual height, and in this respect the case differs from most ordinary beaches, where the force of the sea is, in a great degree, checked by shoal water in the offing.

The Bank has been said to rise very slightly, but regularly, from Abbotsbury to Wyke, where a marked change takes place, the rise being much more rapid towards Portland. The slight rise up to Wyke is undoubtedly to some extent due to the greater depth of water, as compared with that at Abbotsbury, but chiefly to the fact, that the direction, or bearing, gradually approaches more nearly to a right angle with a south-west line. The great increase in height towards Portland has been generally assumed to be owing to a rapid change in the depth of water along shore at this part of the bay. Such a change of depth would undoubtedly affect the height, but it happens that, whilst the bearing is just south-east and north-west for the whole distance between Wyke and Portland, the depth of water, at a cable's length from the shore, is uniformly 50 feet between these points, whereas the Bank, as before stated, is 15 feet higher at the latter place than at the former; it must therefore be due to some other cause. The Author attributes this difference in height to the following cause: From Abbotsbury to Wyke, the streams of ebb and flood run with a velocity of about $1\frac{1}{2}$ knots an hour, and six hours each way, the direction of both being parallel to the beach, or along shore; but at the point where this increased height commences, the stream sets directly across towards Blacknore, and begins to slacken. The greatest velocity, at spring-tides, within a quarter of a mile from the beach, has been proved to be $1\frac{1}{2}$ knots an hour at Wyke,—1 knot midway between this and Portland,—and $\frac{1}{2}$ knot per hour at

Chesil; the Bank increasing in height just in the same degree as the stream slackens. Had the tide-stream continued to run equally strong up to Portland, the effect would have been to check the violence of the sea before it breaks upon the Bank. Those who may have witnessed the effect of even a small current running at about right angles to the breaking waves, will have no difficulty in admitting, that owing to the diminished current of tide close along shore between Wyke and Portland, a much heavier sea will fall in upon this part of the Bank, than would have been the case, had the stream continued to run along shore, with the same velocity as it does to the westward.

Reference has previously been made to the rates of inclination below low-water, and also to the total absence of shingle beyond certain depths. In connection with this, a fact of some importance must be mentioned, as it serves to prove, that shingle does move to a considerable extent in deep water. This is a point which has been often questioned, and is almost invariably denied. In the course of some of the Author's earliest trials by dredging, to ascertain how far the shingle extended under water, it was observed, that at a short distance from the shore, and thence all the way out to the point where the shingle terminated (see Sections, Fig. 3), every pebble was found to be incrusted, on the upper surface, with a species of barnacle—"*balanus balanoides*"—the numbers of these becoming greater, and their size larger, as the depth of water increased. These observations were made in the spring of 1852, after a winter, which, it will be remembered, was remarkably free from heavy south-west gales, and at a time, when off-shore winds had been prevailing for nearly three months, accompanied, as a matter of course, by quiet water in this part of the bay. Since the past winter's gales, which have been unusually numerous and heavy from the S.W., the Author has made a close examination of the bottom, partly with Deane's diving apparatus, and partly by dredging, at the same points as before. He has found that the shingle was perfectly clean and free from incrustation, except that occasionally a pebble was met with having marks only indicating the previous existence of barnacles; and even these were only to be seen just where the shingle terminated altogether. These facts

demonstrate clearly that, at depths of six and eight fathoms, there must have been a considerable amount of motion during heavy gales, and much greater than is generally supposed; for one of two things must have happened, either the barnacles were removed by the movement, and consequent attrition of the shingle, or, a fresh supply was brought in upon that which previously existed there;—from the marks just spoken of, there can be little, or no doubt that their absence is due to the former cause.

In order to determine the depth of water, at low-water spring-tides, into which the shingle extends along the Chesil Bank, and the adjoining coast, special observations have been made, by the Author, as far west as Lyme Regis, and the results are these;—at Lyme Regis the shingle does not extend beyond about 6 feet in depth;—at Bridport Harbour, distant about 8 miles, to 9 feet;—about 2 miles further on, at the point of intersection of the S.W. $\frac{1}{2}$ W. line drawn through Start Point, (before referred to,) it deepens suddenly to 21 feet;—it is found out to 36 feet, or 6 fathoms in depth, at Abbotsbury;—and to 48 feet, or 8 fathoms, at Chesil, immediately to the southward of which it ceases altogether. The marked change which takes place where the S.W. $\frac{1}{2}$ W. line strikes the beach near Burton Cliffs,—the sudden increase of depth at that point,—and its abrupt termination at Portland,—are all facts of considerable interest. It thus appears that shingle will be found at depths of water varying according to circumstances, and that the precise depth at any point, or beach upon the coast will depend,—1st, upon the degree of exposure of that particular beach, or line of shore;—2nd, upon the aspect, or angle which it may make with the bearing, or direction from whence the heaviest seas proceed,—and 3rd, upon the depth of water in the offing.

Owing to the difference of the level between the East and West Bays, and the consequent percolation, or passage of water, through the Bank during very heavy gales of wind from the south-west, a number of gullies—or, as they are called in Portland, "cans"—have been scoured away on the eastern side of the Bank, but more particularly between Portland and Wyke. On such occasions considerable streams of water may be seen, in many places, running through from west to east, carrying the

shingle with them, and thus forming the gullies, or "cans," alluded to. One of the largest existing during the last winter is represented in Fig. 5, which is a plan with contour lines laid upon it. The quantity of shingle which would be required to replace that scoured away, and to make it uniform with the general line of slope, would amount to about 170 tons. The lower end of the "can" is not exactly in the form left by the sea, some portion of the shingle, just above the high-water line in the East Bay, having been filled in to make good the roadway. The water thus passing through the Bank has, doubtless, had the effect of giving, in some degree, the flat slope on the east side; it has not however been the sole cause, as is sometimes imagined. If it be supposed that the Bank were removed, and its re-formation about to commence, there could be no question that, at first, the very heavy seas of the West Bay would throw the shingle in to a great distance on the shore; this distance would necessarily become less and less, as the shingle accumulated, and the Bank became higher; the result would be, a flat slope towards the bottom, with a rapidly-increasing inclination towards the top, just as is found to be the case.

It has been before observed, that the fact of the largest shingle being found, at what has been called "to leeward," is well known in the neighbourhood: this term "to leeward" must however, if applied to shingle, be clearly understood, as relating to the quarter whence the heaviest seas proceed, and not to the winds.

The prevalent notion amongst the fishermen employed on the Bank, and many other practically well-informed persons, is, that the shingle travels from south-east to north-west, and it is this position of the respective sizes which leads them to that conclusion. Judging only by what is seen above water, they say,—"the large pebbles are first thrown up near Portland, and as they become ground smaller by the action of the sea, are gradually washed further and further to the westward, whilst fresh pebbles are being thrown in at the east end, to supply their places." This may appear to be a rational solution of the problem, but it is by no means the true one. There is an apparent confirmation of the prevalent opinion in the fact, that as you go westward, a large proportion of sand is to be found;

this is also attributed to the grinding action of the sea upon the pebbles on the Bank.

The Author has never met with any satisfactory attempt to explain the anomaly, that the large shingle is always found "to leeward," but considers the reason to be simply this, that as a rule, the large pebbles move more readily than the small: however paradoxical this may appear, it is a fact which he has frequently observed, and from which he was induced to draw the following conclusions:—The large pebbles, it must be remembered, are exceptional sizes, and will most commonly be found to lie on the surface; but the small pebbles are so disposed,—by being washed about until the hollows, or indentations are filled up,—as to give the beach a generally even surface. Suppose then, by way of illustration, that a pebble of the size of an orange be thrown upon a beach composed of small pebbles, or gravel, it will soon be seen, that notwithstanding the large pebble has an amount of surface less in proportion to its weight than the small, yet, practically, it exposes a proportionately larger surface to be acted upon by the waves, and consequently, has a greater amount of motion imparted to it; thus, it will be rolled up and down, in a far greater degree than the smaller particles which compose the body of the beach, and which, speaking collectively, form a generally even plane, and expose, individually, but a small portion of their surface to the action of the wave. In the case of small pebbles, with their upper sides forming part of the general surface, either the whole mass must move together, or any single pebble would have to be lifted vertically to some extent, before it could move along upon the slope of the beach; not so with the large pebble already lying upon the surface, this would simply have to be rolled, or borne along, and for the reason before mentioned, would receive a comparatively greater impetus from the waves. The great amount of motion in the large shingle, as compared to that of the small, would be very evident to an observer taking up his position afloat (and as close to the beach as possible), when there is a slight swell prevailing. The existence of sand to the westward, before alluded to, would unquestionably facilitate the progress of the larger shingle, in the manner here described. This sand is derived from the low cliff near Charmouth, and is washed along with the shingle, the pro-

portion travelling eastward becoming less and less. The small quantity of sand found near Portland, is different in its character, and is evidently derived from the pebbles which have been fractured by the violence of the sea; it is only to be seen in patches, after a heavy ground-swell has to some extent scoured away the shingle.

The obvious mode of demonstrating the passage of the shingle, by examining the character of that below the water surface, at several points, has been adopted, and the evidence afforded by the samples so procured is most conclusive, as proving that the shingle travels from west to east.[1] At the Abbotsbury end of the Bank the shingle below the water, is generally very large and spherical in form, whilst at the same point, only small pebbles are found above low-water level. Again, at Portland, the average size of the shingle below low-water is decidedly smaller than that found, under the same circumstances, at Abbotsbury, whilst that on the Bank above low-water is very much larger. The relative proportions of size in the shingle found at the respective levels, and at the different points along the Bank will be seen on reference to the transverse sections, Fig. 3.

It is remarkable, that the large shingle found at about the level of high-water, and such of the large pebbles as may occasionally be found at higher levels upon the Bank, have generally a flatter form than those under water. It is important to notice, that all the shingle near Portland is generally less spherical than that at some distance to the westward, as this proves, that it has been longer exposed to the grinding action of the sea. The small shingle on the top, or crest, of the bank (having its surface large in proportion to the weight) is carried there during the height of the heaviest gales, and is left beyond the action of any receding water. There is another such instance about a mile to the eastward of Weymouth, and doubtless the same thing might be seen on any beach having a similar section.

At one of the meetings of the Institution, during the last Session, it was stated that the largest shingle was found on the

---

[1] The samples here alluded to were laid before the Meeting at the time the Paper was read.

top of the Chesil Bank. The Author opposed this view as erroneous, for it is beyond all question a rule that the smallest shingle is found at the top of the Bank.[1]

An examination at low-water with the wind off shore, or just along the shore, will show, that as a rule, the largest shingle to be found upon any beach, at that particular time, is just about the level of the previous high water, or so far above it as the wash of the previous tide may have extended; and the sizes decrease from this level down to low water. In the case of a beach terminating by a cliff, or wall about the level of high-water, it might with truth, under such circumstances, be said, that the largest shingle was at the top; such, however, would not be the case upon the Chesil Bank.

Mr. Palmer adduces a very ingenious theory, to account for the order of sizes, but it is nevertheless insufficient and unsatisfactory, inasmuch as it is opposed to the unquestionable fact, that the largest shingle is found "to leeward." The reasons already given, to account for the more ready movement of the large shingle, would seem to be the true explanation of this order of size; and the same reasons will account for the fact, that, after the prevalence of heavy on-shore winds, or a "ground-swell," the large shingle will be found to be entirely scoured away from the beach.

An examination of the section, or profile of the Bank, taken at its highest point near Chesil, after a heavy south-west gale, and the subsequent ground-swell, gives a very interesting result. From observations on one, or two such occasions, the Author was induced to believe, that the profile of the Bank would be found to partake of the form of a parabola. A favourable opportunity having offered itself after the gale of 27th December last, levels were carefully taken, and the section thus ascertained, is laid down on Fig. 4. A parabola drawn to the same horizontal and vertical scales as the section of the Bank, has been placed over it, in order to show the remarkably close correspondence of the two. As a further evidence of the great similarity, there is given, upon the same figure, a table constructed upon the supposition, that the parabolic figure was

[1] *Vide* Report of Discussion upon Mr. J. B. Redman's Paper "On the South Coast of England." Min. of Proc. Inst. C.E., vol. xi. p. 205 *et seq.*

laid upon the surface of the beach, in which case the first column would represent the abscissæ,—the second the calculated ordinates, (excepting only, that which is farthest from the vertex, which has been assumed to be the same as the vertical, given by the level,)—and the third, the depths at the corresponding points, measured from the assumed axis of the parabola down to the surface of the shingle, according to the levelled section. This section could not be carried further down on account of the heavy sea running at the time. The precision of the figure, as shown by Fig. 3, up to the level of a point more than 25 feet above high water, gives some idea of the tremendous power of the sea at the time, and the height to which the wave, in its pure form, must have reached: this is undoubtedly due to the great depth of water close in-shore, as the waves fall in upon the Bank, unaffected by shallow water in the offing.

It is known that shingle accumulates upon any beach with off-shore winds, whilst it is carried off, or scoured away, during on-shore winds, and more especially by the ground-swell which follows. Mr. Palmer calls the first the accumulative, and the second the destructive, action; he does not notice them as being in any way dependent upon the direction of the wind, but says, that the difference between the two, is "determined by the rapidity in succession of the waves upon the shore"—his opinion being, that when the waves break in quick succession they cause the destructive action, and *vice versâ*. He says, "When ten breakers arrived in one minute, the destructive action was but just evinced; and that when only eight breakers arrived in the same period, the pebbles began to accumulate." He gives these as instances of the destructive and accumulative action in their smallest degrees. The views here expressed are opposed to the conclusions arrived at from the Author's observations on the Chesil Bank and elsewhere. The rule, as far as one can be formed from the number of waves in a given time, appears to be, that seven, or any less number of waves per minute, indicate the destructive action, and nine, or any greater number, the accumulative action; but no very precise rule can be framed upon this basis. The number of waves in a given time, will undoubtedly, to some extent, serve as a guide to the kind of action going on, but a more certain indication is found, by

watching the course of the water as it falls from the crest of the wave after breaking;—if it falls upon the water which may be returning down the slope from the wave immediately preceding,—as it will do when the waves follow in rapid succession,—this may be taken as an evidence, that the accumulative action is going on; if, on the other hand, the water descends directly upon the pebbles,—as is the case when the waves break at comparatively long intervals, it carries down with it a portion of the shingle, and is, in fact, a case of destructive action.[1] It is evident, therefore, that much must depend upon the rapidity with which the water runs off, or is absorbed; this again will, in some degree, be affected by the slope of the beach, and also by the nature of the materials of which it is composed,—since it may be of shingle only,—entirely of sand,—or a mixture of the two in various proportions,—and as these proportions differ, so will the rate of absorption be found to vary.

In Mr. Palmer's paper, before alluded to, he speaks of having taken the slope of the beach at Folkestone, after a heavy ground-swell, and found that it was, to use his own words, "in the proportion of 1 to 9, nearly, and (with the exception of that part near the summit where there remained a bank of pebbles beyond the reach of the previous tides), the surface of the plane corresponds very nearly with a straight line, which, considering that it is a natural formation, is a fact worthy of notice."

Referring to Fig. 4, an examination of that portion of the beach which lies between the levels of high and low water, will show that it approximates closely to a straight line, the slope being slightly flatter than 1 in 9; and precisely the same inclination has been observed, within the same limits, after a heavy ground-swell. These facts are interesting, when compared with the result of Mr. Palmer's observations. After a continuance of off-shore winds, for two, or three days, the case is very different. Under such circumstances the shingle takes a perfectly uniform inclination, within the limits of the tidal range, and lies generally at a slope of 1 in $3\frac{1}{2}$ to 1 in 4.

It may here be well to recapitulate, as briefly as possible, the

[1] The extent of shingle scoured away from the Bank near Chesil, during the gale of 27th December, 1852, will be seen on reference to Section C, Fig. 3.

chief points of interest which have been noticed, and the deductions which have been drawn in the course of this Paper.

It has been shown,—

1st. That the geological character of the coast-line within the bay, from Portland Bill to Start Point, has been examined in detail, and that the only possible source, from which the shingle of the Chesil Bank can have been derived, is between Lyme Regis and Sidmouth.

2nd. That the cause which operates to transport the shingle from this part of the coast to the Chesil Bank, will be found, not in the tidal currents, but in the wind-waves.

3rd. That the isolation of the Bank is due to the existence of a level, or nearly level, bench of clay, upon which the shingle is thrown in and rests, as upon a shelf.

4th. That the great elevation of the Bank in general is to be accounted for by its exposure, and the existence of deep water close to the shore; and the rapid increase of height between Wyke and Portland, by the heavier seas which fall in there; and further, that these are consequent upon the diminished current of tide along-shore, at that part of the bay.

5th. That the depth of water in which shingle will move varies according to circumstances,—and that in situations which are very much exposed, with the beach lying at right angles to the heaviest seas, and having deep water close in, it may have a considerable amount of motion during heavy gales of wind, in water as deep as eight fathoms at low-water of spring-tides.

6th. That the cause of the large shingle being found, at what is called, "to leeward" upon any beach, is due to the fact of the large pebbles moving more readily than the small, and this fact—although somewhat paradoxical,—has (it is hoped) been satisfactorily accounted for.

7th. That when the wind has been off-shore, or along-shore, (under which circumstances the shingle accumulates), the largest pebbles to be found at any position upon a beach will be about the level of high-water, and that the sizes decrease gradually towards low-water; also that this order of sizes is due to the more ready movement of the large shingle just alluded to.

8th. That after the prevalence of heavy on-shore winds, or a considerable "ground-swell," the large pebbles will be scoured away, and the relative order of sizes will no longer be found to exist.

9th. That most of the large shingle found occasionally about the level of high-water, and all that of a large size, to be met with at the higher levels, is less spherical in form, *i. e.* more flattened, than that which is found under water.

10th. That the shingle found immediately upon the top of the Chesil Bank, and also upon the top of any other beach similarly situated, will certainly be smaller than that found at a lower level; that it is thrown there during the heaviest gales, from having its surface large in proportion to its weight, and is left beyond the action of any receding water.

11th. That by levels taken at the most exposed part of the Chesil Bank, after a heavy gale of wind from the south-west, which is at right angles to its direction, or bearing at that point, the section was found to correspond so closely with the form of a parabola, that its outline might almost be said to be mathematically true.

12th. The different effects of off-shore and on-shore winds have been shown, the former, as a rule, causing the shingle to accumulate, and the latter scouring it away. As the result of a great number of observations, it has been stated that, as far as any rule can be formed, nine, or any greater number of waves per minute, will produce the former action, and seven, or any less number will induce the latter action. It has also been shown, that the most certain indication of the action going on upon the shingle at any particular time, will be found by watching the course of the water which falls from the crest of a wave after breaking; and—

Lastly. That after a prevalence of heavy on-shore winds, the general slope, or inclination of the shingle, within the limits of the tidal range, although slightly curved, has been found to be from 1 in 9 to 1 in $9\frac{1}{2}$, but with off-shore winds the slope is perfectly straight and uniform, within the same limits; the rate of inclination, under such circumstances, being from 1 in $3\frac{1}{2}$ to 1 in 4.

The points which seemed chiefly to demand attention having now been reviewed, it is felt, that this Paper has already extended to a length, so much greater than the Author could have wished, as to admit of no more than a passing notice, of the tremendous violence of the sea breaking upon the Bank, during heavy gales of wind from the south-west. When it happens, as it frequently does, on such occasions, that the water receding from any wave just broken, meets that of the wave next in succession, in its progress towards the shore, the concussion is so great, that an enormous body of broken water and spray will sometimes rise perpendicularly into the air to a height of 60 or 70 feet.

Instances are known, in which vessels stranded on the Bank have been broken up almost instantaneously, by the sea falling in upon their decks and crushing them; a single wave has in this way effected the entire destruction of a vessel of 200 tons. It will, however, sometimes happen, that a vessel coming in on the top of a sea, and with some "way" on, especially near high water, will run so far up the Bank as to escape comparatively uninjured; a case of this kind is given in Appendix A., page 545.

The boats used on the Chesil Bank, are called "lerrets" by the fishermen, and others in the district. A description of them is given in Appendix B., page 545, and the plan in Fig. 6, Plate 2.

In conclusion, and with a view to convey some idea of the tremendous power of the sea, and the vast changes which take place, from time to time, upon the Chesil Bank, the following facts may be adduced:—

After the gale of the 27th of December, 1852, the quantity of shingle, scoured away between Abbotsbury and Portland, was 3,763,300 tons.

By sections taken at the following spring-tides, the quantity thrown in, subsequent to the gale, and between the same points was found to be 2,671,500 tons.

On the 23rd November 1852, the wind, which had been very light during the day, suddenly freshened to half a gale at 4 P.M., blowing from the south and south-west; and at 8 P.M. had almost entirely died away; notwithstanding that its duration was so short, a very heavy ground-swell fell in upon the bank, and the quantity of shingle scoured away during the

night and early part of the following day, amounted to 4,553,000 tons.

Upon taking the measurement five days afterwards, it was found that there had been thrown in upon the bank, during that period, no less than 3,554,200 tons.

The accuracy of these figures may be fully relied upon, as they were arrived at by calculations made with great care, from sections taken for the purpose.

The Paper is illustrated by a series of diagrams, from which Plate 2 has been compiled.

APPENDIX A.

During the height of the gale on the night of the 23rd November, 1824, a sloop, called the "Ebenezer," of about 100 tons burthen, employed in the Ordnance service, having on board stores and heavy guns, bound to Portsmouth, was unable to "weather" Portland, and, as a last resource, was run directly on to the Chesil Bank under canvas. She happened to come in on the top of a sea, and by her momentum was carried on to the crest of the bank, where she remained for some time, and was ultimately launched into Portland Roads. This vessel remained for many years after in the same service. The spot where she lay on the top of the bank is still visible, and is indicated by the letter E on the longitudinal section, Fig. 2.

APPENDIX B.

The boats which are used on the Chesil Bank are called "lerrets," by the fishermen and others in the district. They are of a peculiar build, having great beam (See Fig. 6, Plate 2) and an unusually flat "floor." They are therefore extremely buoyant, and, if properly managed, will live in almost any weather. These lerrets are pointed at both ends, and are propelled by two, four, or six oars, according to size and circumstances, the men pulling "double-banked," but the rowers on one side pull stroke alternately with those on the other, thus giving the boats a tortuous motion through the water. The fishermen affirm, and no doubt believe, this to be the most economical application of their power. Each oar has a block of wood, generally of African oak, fixed to the loom by spikes and a lashing; this block is called a "copse," and has a hole through it to receive an iron "thowl" pin, fixed to the gunwale of the boat, and standing about five

inches above it. This arrangement serves the following purposes:—It prevents the oar being "unshipped" in a heavy sea, and retains it in its place at all times, so that it may be let go at any moment, and can at once be resumed for use when required: this is a matter of great convenience to the fisherman. It serves also, to some extent, to balance the weight of the oar; and as the boats have necessarily to be run up and down the bank for a considerable distance, the oars are laid in a line, the length of the oar being placed at right angles to the line traversed by the boat's keel, so that she is run along upon the copses, which prevent her sinking into the shingle, and by the application of a little tallow to the copses and keel of the boat, the friction is reduced to a minimum, a point of much consequence with a heavy surf on the Bank, when it is all-important that the boat should be run beyond the line of breakers with the utmost expedition.

The great, and perhaps only, disadvantage to the fishermen in the use of the copse is, that it does not admit of the oar being "feathered."

For the purpose of hauling the boats in upon the beach a "start-rope," as it is termed, is rove through a hole in the keel, just before the foot of the stern-post; the boat is backed in by the rowers, and hauled up stern foremost. The start-rope being thrown to men on the beach, before she is allowed to come in, these men commence hauling before the boat touches, in order to take advantage of her "way," and thus haul her up quickly out of the reach of the surf. These boats are invariably launched head foremost, the hands being ready at the foremost oars to keep the boat's head to the sea, immediately on taking the water.

Each lerret carries two sails, a "lug" mainsail, and "sprit" mizen. Those in general use average from three to four tons burthen. The Portland fishermen frequently launch and haul in these boats through a surf such as few other boats could live in, and they do this in a manner which is highly creditable to their skill and courage.

Mr. COODE stated, that he had used Deane's diving-dress, and had been down in 10, or 11 fathoms of water, for the purpose of examining the bottom, and he had found the line of demarcation between the shingle and the sand to be very clearly defined at their junction. The greatest depth at which the sand and shingle were found to join was 50 feet on the west side of the bank. The bed of the East Bay was of Kimmeridge clay. There was no trace of the East and West Bays ever having been in connexion, even at the most remote period. The earliest notice of the Bank that he had met with, was that by Leland, in 1546. In 1824, an ordnance smack, laden, was carried by the sea right on the Bank, and the easiest way to extricate her was to launch her into the East Bay. With regard to the tide stream, up to Wyke from the Start Point, the tidal currents ran equally, upon flood and ebb, for about 6 hours, and at the rate of 1½ knot each way. The tide in the Race of Portland ran 6½ knots an hour. This was, however, purely local, and was due to two causes, one being the indraught into each Bay, according as the tide was flowing, or ebbing, the other being the rapid deepening of the water from 6 fathoms to upwards of 30 fathoms, this increase of depth taking place in little more than a quarter of a mile. The shingle at Weymouth was derived from the Cliffs to the west of Lulworth, and might be mentioned as a solitary instance of the travel of shingle from east to west.

Mr. BABBAGE thought an inquiry into the form assumed by pebbles under water, under certain circumstances, would lead to useful results, and might throw some light on such formations as the Chesil Bank. At the east end of the Bank, the shingle appeared to be comparatively flat, whilst at the west it assumed almost a spherical form. He believed that the large pebbles would generally be found at the level of low water. The collection of facts recorded in the Paper was so large and important, that both engineers and geologists were equally indebted to the Author.

Mr. BIDDER, V.P., observed, that the Institution was seldom favoured with so good a Paper; and if it reflected credit on the Author, it would also extend the reputation of the Institution. It was not alone valuable for the inferences drawn from the facts which had been brought together, but it evidenced great research and much skill in observation. The facts advanced, in

some cases corroborated his own observations, whilst in others they corrected his opinions. But however acute and scientific the observations might be, on this particular locality, it would not be prudent to receive the conclusions, as applicable to beaches in general; in fact, it would be safer not to generalize upon this, or any other isolated case. The relative positions of the different-sized pebbles on a beach, depended upon the depth of the water, and the force of the waves. On a long shelving shore, like some parts of the coast of Kent, where the waves could only act upon the beach at, or about the time of high water, the larger pebbles were found near the top, after the occurrence of storms; because under such circumstances only, did the waves exert sufficient power to break heavily upon the beach. Under light winds, the force of the waves was expended in the shoal water, before reaching the beach. The Author of the Paper had shown, that the motion of shingle was derived from the wave of translation; and he had confirmed the views previously entertained, as to the effect of on and off-shore winds, and as to the slanting wind causing the wave of translation. The late Mr. H. R. Palmer's observations "On the Motions of Shingle Beaches,"[1] were made upon a very different kind of shore to the Chesil Bank. The great problem to be solved by the engineer, was, the condition under which a harbour could be maintained where there was a travelling beach. He only knew one instance of the kind, and that was at Lowestoft. The works there had been completed between six and seven years, and during that time they had suffered no injury, nor was the entrance to the harbour in any way impeded. But there the circumstances were quite peculiar and accidental. On the north side there was a fine clean sand, and on the south a clean beach, but thin. The conclusion he arrived at from these facts, was, that the travel of the shingle had spent itself at that point. Of the sand, 25,000 tons were annually used, for ballasting the vessels frequenting the port, and about the same quantity was washed up, so that the bank remained the same. Only ten miles off, at Yarmouth, the sand was continually accumulating, and forming a bar. At Aldborough, at the mouth of the River Or, the prevailing wind being from the south, there was a bank,

---

[1] *Vide* Phil. Trans. Royal Soc. 1834. Part II., p. 567.

somewhat similar to the Chesil Bank, forming an isthmus nine or ten miles long. Here the water deepened gradually, and he had no doubt a careful examination would confirm the Author's opinions. If the project which was before Parliament last year, for forming a harbour at Aldborough, by cutting through the bank beach, had been carried out, it would, he believed, have been filled up again with shingle very speedily.

Sir JOHN RENNIE said, the remarks of Lamblardie, a French engineer, on the movement of shingle on the coast of Normandy,[1] were, perhaps, amongst the earliest of the kind on record. Smeaton and Rennie had also made some observations on the beach at Dover. Lamblardie arrived at much the same conclusions as the Author of the Paper under discussion, and so also had the late Mr. H. R. Palmer, who did not appear to be aware of Lamblardie's pamphlet. These conclusions were, that the shingle was moved, principally, by waves due to the wind, and not to the tide; mere currents were not sufficient; it needed the successive impulse of the waves. Lamblardie also stated, that the waves acting in-shore undermined the cliffs, large masses of which were brought down, and if of chalk, or loose material, were soon dissolved, and the pebbles rounded by attrition; then where the wind struck the shore at an angle of 45°, the beach was moved on. When the waves acted in a direction parallel to the shore, the friction prevented the travel of the beach; the amount of this travel must, of course, at all times depend, on the supply of shingle from the cliffs, and on the direction and power of the wind-waves.

The most important engineering problem was, how and where to make a harbour in a travelling-beach. If the beach could be allowed to move on unmolested, or if it was supplied in such moderate quantities that its removal could be easily insured, the works might succeed; and even if the beach supplied any drift, the works could be extended seawards, so as to be beyond any probable injurious influence, and a dredging-machine could be employed, for removing the alluvial deposit. On the other hand, should the beach be in large quantities, then the case might be different. He recommended that careful observations should be made along the coast, with the view of finding such spots as

[1] Mémoire sur les Côtes de la Haute Normandie. Par M. Lamblardie. Tract 4to.

Lowestoft, where two forces neutralizing each other, rendered it peculiarly favourable for harbour works. Still even in designing them considerable skill was requisite to prevent deposit.

Mr. HAWKSHAW said, the direction of the tidal wave appeared to be nearly identical with that of the prevailing wind-wave. He thought there were certain depths at which the waves would not act upon the shingle, and that by extending the piers into that depth of water, the entrance to a harbour would not be effected by the travel of the beach. No general rule, could, however, be laid down for making harbours in a travelling-beach.

The sea appeared at one time to have washed up to Wyke and Fleet, before there was any such thing as the Chesil Bank. It would be very interesting if the Author of the Paper, in whose views he generally concurred, would devote some attention to the elucidation of the circumstances under which the Bank began to be formed. Viewing the relative position of the geological strata of the coast, to the westward of Portland (Plate 2, Fig. 1), it would be seen that, the series overlying the Devonian rocks were the new red sandstone, the oolite, and the greensand and chalk. Now if we imagined a time when the sea was washing the Devonian rocks, and not reaching to the chalk, it would be evident that no material, such as now constituted the Bank, could be brought down to form it. This state of things might have occurred, as all geologists would admit. As the waves washed away the lower series, those particular pebbles which had since formed the beach would begin to be supplied, and then, when the resistance between the stones just equalled the force of the waves, the Bank would begin to be formed. It was probable, that the extent of chalk exposed to the action of the waves, had, at a former period, been much greater than at present; and that the disintegration of the underlying green-sand, had expedited the fall of the chalk and flints, and thus supplied the material for forming the Bank.

Mr. JOHN MURRAY observed, that the height of the crest of the Chesil Bank being generally about 40 feet above high-water, the materials of which it was formed could not, in his opinion, have been all brought from so small a recess as the West Bay. He thought that the coast westward of it, as far as the Land's End, and the contour of the whole sea between England and

France, must be looked at, to account for that formation which had puzzled both geologists and engineers. The deep wave travelled with greater power and velocity than the shore wave. From the Lizard to the Start Point, and from the Start to Portland, the set of the tidal wave was towards the Chesil Bank. The direction of the wave was changed on entering the West Bay, so that the whole matter in suspension was thrown backwards towards Bridport; naturally, the larger pebbles remained at Chesil, whilst the smaller ones travelled westwards. In calm weather there would be little, or no action; but when accompanied by wind it would be considerable. He had traced the coast, and had found that at Lyme and at Weymouth, the pebbles were moving in different directions.

On the east coast, the shipping which frequented the coal ports, cast out at sea, particularly in fine weather, great quantities of ballast, in water 10 to 20 fathoms deep. The greater part of this ballast was composed of sand and pebbles, dredged from the Thames, with chalk and other matter foreign to the East Coast. After storms the shore between the Tyne and Hartlepool was strewed with these pebbles, which could only have been brought there by the action of the waves at the depths stated.

In the construction of the groynes at Sunderland to arrest the passage of the sand and shingle, the cross action of the waves, influenced by a ledge of rocks, caused the deposit to take place on the opposite sides of the groynes.

Large and small pebbles with sand were, in his opinion, moved at greater depths, under water, than was generally believed. M. Virla, by experiments at Cherbourg, found that the agitation of the waves extended to the bottom of the sea there. M. Vionnois, by observations in the Bay of St. Jean de Luz, ascertained that the agitation during storms had been felt even at the depth of 300 metres. Brémontier stated, that on the sand-bank of Newfoundland, the agitation descended even to 160 metres, and remarked that south of the Cape of Good Hope, the sea was broken, caused by the using of the bottom, where it was upwards of 200 metres in depth.

Mr. Joseph Gibbs could not allow the opportunity to pass, without expressing his dissent from the view of the Author, that large pebbles, when travelling under water, would be

acted upon more easily than small ones, because of the greater surface presented by the former to the action of the waves. Such was not the case. The movement of the beach in question was not so much due to the ordinary flow, as to what might be termed submarine currents, which had the power of carrying pebbles along the shore at great depths until the waves cast them up as shingle.

It was an interesting question to consider, from whence the shingle of the Chesil Bank had been derived, and whether that quantity of beach could have proceeded from the débris of the West Bay. He was certainly inclined to believe, that it was sufficient to produce it. Moreover, its geological character seemed to corroborate this opinion.

The travel of pebbles was alternately up and down a bank, and along with each succeeding wave. The action of the wave, however, was never directly parallel to the bank, but, generally, at a considerable angle to it. It followed, that the shingle would travel in a direction indicated by the oblique action of the wave. The movement of the shingle was influenced, to a certain extent, by the set of the tide along the shore. The fact of the larger pebbles being at the top of a bank, and the smaller ones at the bottom, whilst the foot of the bank was composed of sand only, or the smallest pebbles, might easily be accounted for. It should be borne in mind, that the wave in deep water had only an apparent velocity, which was converted into an absolute velocity when the trough of the wave touched the shore. It was then that the wave mounted up the beach, to a height commensurate with the dimensions of the wave, and above the level of the sea, carrying with it the shingle, stones, and sand. The velocity of the wave was speedily arrested by the gravity of the water, and then its retrocession commenced; but as the velocity and power of the wave of retrocession were not sufficient to carry back all the shingle, the larger pebbles remained on the top of the bank, whilst the sand and small pebbles were drawn to the foot of the bank. A slight obliquity in the oscillation of the wave caused the travel of the beach, from those places where the strata existed, which produced the material of which it was composed.

Mr. Rennie had some years ago taken sections of the Chesil Bank, when he arrived at the conclusions, that the highest

beach was the result of storms, and that the terraces marked the various states of the tides. He agreed in the opinion, that the most probable source of the beach was the chalk cliffs in the West Bay, and that the cause of the accumulation was the revolving tide from the westward, the wind giving the particular direction. Near Lyme, the beach stretched only to a short distance from the shore; but it became gradually more extensive as it approached Portland. He had great doubts as to whether shingle moved much. He believed the late Mr. H. R. Palmer was correct in the opinion, that the largest shingle was generally to be found at the top of the beach.

Captain Fitzroy, R.N., thought that some consideration should be given to the direction of the currents on this particular part of the coast. In the West Bay, the stream of flood tide set round the bay, to the eastward; the ebb setting straight out of the bay. On the other side of Portland Bill, the tidal stream set in a contrary direction, so that all that was liable to be moved was drifted to the westward. These two streams —the flood on the west, and the ebb on the east—neither of which ran parallel to the main shore, combined to throw up a ridge, to which the projection of the rocky Bill of Portland gave support; and this had led to the formation of the curious Bank, which had been so ably described. The absence of Portland Bill would have permitted the free passage of shingle, but that point checked the travel of beach from each side, and caused the Bank to be formed. That the detritus came from the chalk formation, and not from any great distance, might be shown from other analogous cases along the coast, wherever there was a predominance of chalk, or gravel, in progress of destruction. On referring to Dungeness Point, it would be seen, that it had evidently been carried from Beachy Head. Little, or no shingle was found on a rocky coast; nor was there an instance, on any coast, of great masses of shingle, where they were not derived from the wearing away of some deposit in the immediate vicinity. He did not think that shingle travelled at depths of 40 or 50 fathoms under water. Shingle was never found in deep soundings, but only oaze shells and sand. The beach being supposed to be derived from the immediate neighbourhood, the large and the small together, the impetus of the larger stones would carry them

furthest, where their bulk and weight would cause them to remain, whilst the smaller ones would be partly removed by each receding wave. It certainly was the case that, on all beaches, the largest stones were moved, by water, the greatest distances. Before the Plymouth Breakwater was finished, and during the progress of the works, large blocks of stone were thrown up, and carried over the works to a very great distance; proving that the water had sufficient force to act upon large stones. The tidal rise and fall of the ocean, had no power to move any solid body onwards. The current caused by the tidal-wave might exercise force, but it was the wind-wave that acted most powerfully.

Mr. Coode admitted that, during on-shore winds, the largest pebbles were found at the top of beaches against a cliff, or a wall. In the case of the Chesil Bank, however, and in all cases where the shingle was not so checked, the largest sizes would not be found on the summit, or crest; but with a rising tide, and at those times when the shingle was accumulating, the largest would generally be found at the water line. With the wind at an angle of about 45° with the line of shore, the greatest amount of travel, or onward movement was observed, but the size of the shingle, more especially, was governed by the amount of undulation.

The Chesil Bank was due, he believed, to the bench of Kimmeridge clay, which he had found, (on the east side only,) at 3 feet under low water. The Bank was formed from the detritus of the cliffs to the westward, and it was remarkable that not a chalk flint could be found, from the Bill to Chesil Town. He did not think the shingle could be brought there by a return, or tidal current. The sandy material was quite sharp, and not rounded; but the sharp, shattered flint, noticed by Dean Buckland, and Sir H. De la Beche, would certainly have been rounded if it had been moved. The terraces were formed by the undulation of the wind-wave, the direction of the wind determining their line. The tides along the face of the Bank in the West Bay, up to Wyke, appeared generally to run each way for six hours, and with equal strength in each direction, so that it did not seem possible, that the tide stream could affect the travel of the shingle along the shore.

Professor Airy, through the Secretary, whilst adding his

testimony to the general value of the Paper, said he wished to acknowledge one point as peculiarly valuable, namely, the ascertaining of the existence of the clay bank underneath, which had undoubtedly determined the line of the Bank from Portland. The determining cause of this direction, and of the vacuity of the "Fleet" had now been settled. In a letter to Sir C. Lyell, a year ago, he had suggested that there must be a bank, or at least a shoal enough to make the sea break. He was under the impression, that the Author's examination of the cliffs and quarries was not sufficiently extensive, or close, to enable him to say positively that Portland could not furnish the materials. He remarked on this freely, because it was critical, as regarded the origin of the Bank, and because it appeared to be contradicted by other accounts. For instance, in Conybeare and Phillips' Geology (page 174), there was a complete section from the west side of Portland, in which there were "many layers of flint and stony rubbish 6 feet;" "many layers of flints and unserviceable stones 55 or 60 feet." Until this want of materials in Portland was proved, more certainly than it appeared to be at present, he must retain the opinion, that the Bank had travelled from Portland.[1] There was nothing more remarkable in this, than in the cases of other bays, with cliffy terminating promontories. Thus, at Caswell Bay (where the tide ran rapidly past), after a gale from the west, or southwest, the pebbles from the cliff points were rolled towards the bight of the bay, and were there ground into sand. Although a swell might roll up the centre of the English Channel, yet there was a tendency in all such places, for the direction of the waves to change gradually, as towards the general line of shore, and to roll pebbles that way. He quite agreed in the opinion that very little was ascribable to the action of the tide.

Mr. Coode, through the Secretary, remarked, that it was not without a close examination, and an intimate knowledge of all

---

[1] In a later communication to the Secretary, Professor Airy stated that the evidence adduced by Mr. Coode, as to the mineralogical character of the pebbles, and their original connexion with the strata at the western extremity of the Bank, now appeared quite satisfactory. In consequence, his own opinion had been entirely changed. He regarded the necessary inference, that the large pebbles travelled further than the small ones, without undergoing serious degradation on their journey, as very important.—Editor.

the strata in the Island of Portland, that he had ventured to state, that the materials composing the Chesil Bank could not have been derived from that source. The shingle of the Chesil Bank was entirely different in character from any of the strata to be found in Portland. He did not mean to say that there might not be found occasionally a pebble from thence; such were, however, but very rare, and even these were only to be seen within a mile, or so of the south-east, or Portland, end of the Bank. Looking at the great mass of the shingle, it consisted, first, and chiefly, of chalk flints (many with the chalk still remaining in the cavities); next, in point of number, of pebbles from the new red sandstone formation, and many from the neighbourhood of Budleigh Salterton, which had red marks resembling blood-spots, and were very peculiar. There was also a jasper, frequently resembling some of the Devonshire limestones, which though small in proportion, when compared with the chalk flints and sandstone pebbles, yet far outweighed, in point of number, those which were easily distinguished as having been derived from Portland. In a paper "On the Geology of Weymouth and its Neighbourhood," by Dean Buckland and Sir H. De la Beche, read before the Geological Society in 1830,[1] a section was given of the cliff at Blacknore Point, on the west side of Portland, and facing the West Bay. With the exception of some beds of Kimmeridge clay and bituminous shale, found at the north-east end of the island, it represented the whole of the strata in Portland, from the surface down to the sea level. What Conybeare and Phillips had described as "many layers of flint and stony rubbish 6 feet," also "many layers of flints and unserviceable stones, 55 or 60 feet," was called by Buckland and De la Beche "compact and chalky limestone with chert" and "sandy limestone with chert," also "rubbly beds with chert." As there had been many thousands of tons of these beds quarried for the Breakwater, within the last two, or three years, he might perhaps be allowed to say, that the latter was the more exact description of the two. The character of this chert, or flinty matter, which contained vast quantities of shells, and chiefly the "Trigoniæ," was so entirely different from that of chalk flints, that one could

[1] *Vide* Journal of the Geological Society of London.

not be mistaken for the other, even when the former might be found in the shape of rounded nodules, among the shingle on the Chesil Bank. The strata throughout Portland were, with the exceptions before named, the same in character as those shown in the section at Blacknore. There was, however, a difference in the elevation above the sea level. At the north end of the island, the calcareous slate and Portland stone would be found 500 feet in height, and at Blacknore about 350 feet; whereas at 'the Bill' these beds dipped into the sea, the inclination being pretty regular from north to south. Having regard to the geology of Portland, and the character of the shingle of which the Chesil Bank was composed, he was confident that its origin must be looked for elsewhere, than in Portland. Further, he had examined the whole of the surrounding district minutely, and was fully convinced of the accuracy of the views advanced in his Paper on this point.

Mr. RENDEL, President, said, it was evident so much interest had been excited by the Paper, and by the valuable facts laid before the meeting, that he wished other Members would imitate the example of the Author, and transmit to the Institution the results of their observations, on the shores adjoining the works under their charge. By so doing they would not only benefit the Institution, but would advance the best interests of science. It would be found that each part of the coast had certain peculiarities of its own, which required to be studied; and that each demanded special treatment, guided by intelligent observation of those peculiarities, and of the geological character of the cliffs, or shore in the neighbourhood. It was dangerous to generalize too much, or to be too precipitate in drawing inferences.

May 10, 1853.

JAMES MEADOWS RENDEL, President, in the Chair.

The discussion upon the Paper No. 895—"Description of the Chesil Bank" (Portland), by J. COODE, M. Inst. C.E., being resumed, was extended to such a length, as to preclude the reading of any other communication.

May 17, 1853.

JOSEPH LOCKE, M.P., Vice-President, in the Chair.

No. 897.—"On the Caloric Engine." By Charles Manby, M. Inst. C.E. (Secretary.)

At meetings of the Société d'Encouragement pour l'Industrie Nationale, on the 26th January 1852, and at the Académie des Sciences, on the 2nd February of the same year, M. Galy-Cazalat entered upon an examination of Ericsson's caloric-engine, assuming it to be composed of the following parts:—

1. A reservoir of compressed air, which when heated acted as the steam in a single acting engine.

2. A cylinder with a working piston.

3. A feed cylinder, whence is forced into the compressed air reservoir, as much air as quits it, to fill the working cylinder.

4. Another cylinder resting upon and receiving the direct heat of the furnace.

5. The "regenerator" or "economizer," a passage filled with layers of fine metallic web, in which the hot air, whilst traversing the apertures, deposits a portion of its heat in descending; the cold air, subsequently introduced, taking up the heat left in the metal.

The two contrary successive currents, of the hot air which is cooled, and of the cold air which is heated, in their respective passages through the metallic web, are governed by a vessel called the "regulator."

In the preamble to his English patent, taken out under the name of Edward Dunn, December 26, 1850, Mr. Ericsson states that "the invention consists, in producing motive power by the application of caloric to atmospheric air, or other permanent gases, or fluids susceptible of considerable expansion by the increase of temperature,—the mode of applying the caloric being such, that after having caused the expansion, or dilatation which

produces the motive power, the caloric is transferred to certain metallic substances, and again retransferred from these substances to the acting medium, at certain intervals, or at each successive stroke of the motive engine; the principal supply of caloric being thereby rendered independent of combustion, or consumption of fuel accordingly; whilst in the steam-engine the caloric is constantly wasted, by being passed into the condenser, or by being carried off into the atmosphere. In the improved engine, the caloric is employed over and over again, enabling me to dispense with the employment of combustibles, excepting for the purpose of restoring the heat lost by the expansion of the acting medium, and that lost by radiation also, for the purpose of making good the small deficiency unavoidable in the transfer of the caloric."[1]

These passages would have led to the idea of a perpetual motion, but that the study of the well-known scientific laws applicable to the case, demonstrate the erroneous principle on which the presumed economy of the caloric engine is based.

The elastic power of gases is solely due to the heat, which communicates a repulsive force to their particles. Now, since the combination of a greater, or less quantity of caloric with a definite weight of gas, produces a greater, or less force, it is necessary, in order to remove mechanically this caloric from the gas, that a greater, or less, amount of power, should be employed. When, therefore, a volume of air is confined beneath a piston in a cylinder, an equilibrium exists between the force tending to press the piston against the air, and the caloric which imparts to the air the resistance opposed to the piston. If the compressing force is increased by a quantity P, the air is compressed until its increase of resistance is equal to P, and a corresponding quantity of caloric is disengaged. This quantity measures exactly the increase of resistance; for if the increase of force P is suppressed, the caloric disengaged becomes a reacting force equal to P, which causes the air to resume the volume it possessed under the initial pressure.

The increments of heat which measure the increments of resistance, in the states of equilibrium of gases, under increasing pressures, are equally found in the increments of resistance opposed to their velocity of efflux. It has been demonstrated

[1] *Vide* Repertory of Patent Inventions.—Enlarged Series, Vol. XVIII., p. 93

by experiment, that the air which escapes from a reservoir, through an opening, under any given pressure, does not alter its temperature, although it may increase in volume. It follows, then, that heat is produced by the resistance which the atmosphere and the construction of the opening oppose to the efflux of the air, and that this heat is the more considerable as the difference between the pressure and the resistance (which difference produces the velocity of efflux) is greater; hence, with the reciprocating motion of a piston in a cylinder, the caloric carried off by the motive fluid, air, or steam, in escaping, cannot be partly retained by a solid filter, without developing an equivalent resistance which annuls the anticipated economy.

This deduction from physical laws is directly at variance with the performance of the caloric ship "Ericsson," as asserted in the statements that have reached Europe. The engines of that vessel are said to be composed of two similar sets of apparatus, in each of which the working cylinder has a capacity of 915 cubic feet,[1] the fire cylinder of 457 cubic feet, and the meshes of copper wire contained in the "regenerator," have a total surface of 4,900 square feet, and weigh 33,000 lbs.

It is affirmed that this colossal engine, of 600 H. P., only consumes 6 tons of coal in 24 hours; whereas the engines of the best steam-vessels employ about ten times that quantity. It is conceived that it will not be difficult to demonstrate, that this statement cannot have taken into account the fuel consumed in laying up a store of caloric, upon and by which the engines have been partly worked, during the evidently too short trials which have been made.

It is well known, that the caloric given out by 1 lb. of air, in cooling 1 degree, is sufficient to add 1° of temperature to 2·8 lbs. of copper. Assuming this as a principle, it is easy to calculate the caloric which the metallic gauze of the regenerator abstracts from the volume of air passing through it into the atmosphere, when the piston descends; as well as the quantity which it restores to the current of compressed air, on returning in the opposite direction.

Suppose, first, that the regenerator receives no heat directly from the furnace, and that the motive air is maintained at the

[1] All dimensions, weights, and temperatures are here expressed in equivalent English measures.

temperature of 521·5° (Faht.) which is necessary to double its volume at 32°. Then let it be admitted, that the initial temperature of the wire-gauze ,as well as the receiver of compressed air, and the atmosphere, is 32°. Finally, let the resistance encountered by the currents of air, and also the increase of temperature imparted by the small feed piston to the air, (in compressing it to the extent of two atmospheres, previously to injecting it into the recipient, namely, by raising it from 32° to 176°,) be omitted from the calculation.

Then 915 cubic feet of air at 521·5° being equal in weight to half that bulk at 32°, and weighing 37·5 lbs. with the barometer at 30 inches; when this volume of air is compressed to 2 atmospheres, it weighs 75 lbs. Calculating according to what are contended to be the erroneous views of Captain Ericsson; at the first descent of the working piston, the air expelled from the cylinders weighing 75 lbs. its temperature should diminish 486·5° in heating the 33,000 lbs. of copper web 3·08 degrees. When the piston re-ascends, the 75 lbs. of air which pass from the receiver through the wire-gauze at 35·08°, lower its temperature to 35·04°, in raising the air from 32° to 35·04°. At the second stroke of the piston, the regenerator is raised to 38° by the air discharged, and is lowered to 37·96° by the entrance of the air from the receiver. And thus continually, until the metallic meshes impart to the current of cold air as much caloric as they abstract from the hot air.

Calculation demonstrates that this equilibrium will take place, when the temperature of the regenerator is at 277°, before the passage of the cold air. From this time, the action of the machine becomes regular, and it consumes at each stroke of the piston, 277 − 32 = 245° of heat, which the discharged air carries into the atmosphere.

To realize this considerable economy, much less, however, than that asserted, it would be necessary that the air discharged should traverse the wire gauze without cooling by expansion, *i. e.*, should preserve the elastic force of two atmospheres, which it had in the working cylinder. Now this force diminishing to the sum of the resistances of the atmosphere and of the regenerator, opposed to it, the sensible heat which measures it must diminish, also, by the entire portion employed in augmenting the volume of the gas, without communicating itself to the

copper-wire gauze. It results from this, that every volume of air discharged, carries into the atmosphere nearly the whole of its caloric, which becomes latent in expanding to double its volume. The insignificant portion which it takes up in conjunction with the copper, in proportion to their respective weights and capacities, corresponds to the difference of the diminution of its volume.

To find the mean temperature of the regenerator, before and after the passage of the air:—

$$t'' = \frac{tP + T\,(C + P)}{C + 2P}$$

$$t' = \frac{TP + t\,(C + P)}{C + 2P}$$

In which

P represents the ratio of the weight of the copper to that of the air;

C, the ratio of the specific heat of air to that of copper;

T, temperature of hot air;

t, ,, cold air;

t'', the mean temperature of the regenerator, after the passage of the hot air;

t', the mean temperature of the regenerator, after the passage of the cold air.

When the furnace heats, at the same time, the regenerator and the chamber, designated the expansion-heater, (chauffeur de détente,) the wire-gauze may be raised to the limiting temperature, which is 521·5°; in this case the air of the receiver has imparted to it a greater amount of caloric, inasmuch as the wire-gauze is raised to a higher temperature, and it receives less from the furnace, to raise it to its ultimate degree of heat.

Notwithstanding these objections, which in the interest of science others deem incumbent to raise, after examining the description of these machines, and the accounts of their trial voyages, as transmitted to Europe, it must be admitted that Captain Ericsson has conferred a benefit on society, by this attempt to introduce heated air as a motive power, and he has, in following in the steps of the Messrs. Stirling, worthily maintained the reputation for ingenuity which he gained in his early labours in railway locomotion with the 'Novelty,' and in marine propulsion by his experiments on the substitution of the screw

for the paddle-wheel. There appears to be at present so much doubt of the utility of the regenerator, that it would be wise to abandon its use for a time, and by trials with a more simple form of caloric engine, establish the fact either of the superiority, or of the inferiority of heated air, in comparison with steam, as a motive power.

In this sketch the views of M. Galy-Cazalat have been closely adhered to, and they have only been brought forward in deference to the expression of the wishes of the President at a previous meeting.

No. 892.—"On the Principle of the Caloric, or Heated Air Engine." By James Leslie, M. Inst. C.E.

The following observations are intended to show, that the "regenerator," as it has been called, but which ought more properly to be termed the "economizer," is based on true principles, and is attended, in practice, with real economy of heat, and consequently of fuel—that Messrs. Stirling's Air Engine, with its economizer, has precedence, in point of date, of Capt. Ericsson's Engine—and that the former is free from several of the objections that have been urged against the latter, and is, on the whole, decidedly superior to it.

It was admitted, in the recent discussion at the Institution,[1] that the air is cooled, in passing one way, and is heated in returning the other way through the "regenerator;" but it was at the same time denied, that this alternate heating and cooling was attended with any useful, or economical result.

The admission and the inference would appear to be quite inconsistent, unless it be maintained, and can be shown, that the mechanical power required to drive the air through the passages of the regenerator, is greater than any advantage to be derived from the alternate heating and cooling; for that some advantage is to be gained by the heating being effected, in a great measure, by means independent of the heat of the fire, is surely not to be denied, unless it be attended with some countervailing loss, or disadvantage.

---

[1] Vide ante, page 312.

It has been found in practice, that the force required to drive the air through the passages of the regenerator, is very small indeed, and that it does not increase in proportion as the density of the air is increased. It could also be easily shown, by an apparatus available for the purpose of making the experiment, that by the removal of the regenerator, the Air Engine would become almost entirely deprived of its power, and that its economy would be entirely gone.

The principle of the regenerator can be best explained by a quotation from a description by the Rev. Dr. Stirling, with whom the first idea of it originated.

"To demonstrate the efficiency of the "regenerator," or as it might more properly be called the "economizer," we only require to assume as an axiom, what is universally known and believed; that if two bodies of unequal temperatures be brought into contact their temperatures will speedily be equalized. We also require, as in other physical demonstrations, to lay out of consideration all circumstances that are not essential, such as the gradual dissipation of caloric by radiation &c. It will also simplify the demonstration if we confine our attention to the change produced upon the temperature of the air, and suppose that of the parts of the apparatus to remain invariable. This approaches very near to the truth, even in practice, since the capacity for caloric in the apparatus must be vastly greater than that of the mass of air to be heated and cooled."

"Now let **A** be a minute portion, or particle of air, at a temperature of 50°, and let **B C D E F G H I K L** be points, or portions of the economizer having the temperatures respectively attached to them. Let **A** be brought into contact with **B** and it will immediately acquire the temperature of 60°, let it touch **C** and it will be raised to 70°, and so on, till at last, by contact with **L**, it acquires the temperature of 150°, having been heated in all 100°, and having taken only 10° from each point or body in the series. The same thing will also hold good in all the successive particles of air which compose the whole mass to be heated.

A	
B	60°
C	70°
D	80°
E	90°
F	100°
G	101°
H	120°
I	130°
K	140°
L	150°
A'	

"Suppose farther, that by any means the temperature

(of **A'**) has been raised to 160°—has attained its maximum—and requires to be cooled. For this purpose let it first be applied to **L** and it falls to 150°, then to **K** and it becomes 140°, and so on, till at last meeting with **B**, it is cooled to 60°. It has thus lost 100° imparting only 10° to each of the points to which it was applied. If now by any means 10° be abstracted from it, it will be reduced to its original temperature of 50°. In the process of being heated it has imbibed 10-11ths of its maximum temperature from the bodies represented by **B C D**, &c. and in process of being cooled it has returned the very same quantity to these bodies, distributing its caloric equally, and giving 10° to each member of the series.

"Let this process be repeated and it is evident that at every successive heating the air requires only 10° to be added to the temperature acquired from the series of bodies **B C D**, &c., to raise it to its supposed maximum of 160°, and at every successive cooling it requires 10° to be abstracted to bring it to the original temperature of 50°. And thus it appears, that by applying air successively to a series of bodies regularly increasing in temperature, and moving it alternately from one end of the series to the other, it may be *heated and cooled ten times*, with an expenditure of caloric which would barely have heated it once, if it had been applied at *once*, to the hottest body (*i. e. beyond the series*). It is evident also that if the series had been composed of twenty points, or bodies, having a difference of temperature of 5°, the air might be *heated and cooled twenty times* at no greater expense of caloric." Nay it is evident, that by multiplying the members of the series *indefinitely*, air could be heated and expanded and made to do work at *no appreciable expense*.

"But let no mathematician be alarmed with the idea of a perpetual motion, or the creation of power. There are many enemies to contend with in the air-engine besides friction, which alone prevents perpetuity in some mechanical motions. We have no means, without consuming a part of our power, of applying the air so closely to the apparatus as to make it absolutely assume the temperature of the bodies to which it is applied.

"There is therefore a loss in the very act of heating and cooling. The change of temperature which takes place in

each of the economizing bodies, during the passage of the air, though small, yet prevents the *absolutely* uniform heating of the whole mass, and thus causes waste.

"But the greatest enemy of the economizing principle, is the continual passage of caloric from the hot to the cold parts of the engine, by radiation, conducting, &c., which requires a continual supply of caloric, to maintain the proper temperature of each. This defect, however, is not peculiar to the air engine, and by multiplying the steps by which caloric must make its way in escaping, and by opposing various obstacles to its progress, we can so detain it as to make it frequently perform the duty of expansion, before it altogether escapes."

Dr. Stirling might have added, as a more convincing proof, and more easy of comprehension than any abstract reasoning, that the machine really did act for a number of years most efficiently and economically, which it could not have done, had there been a fallacy in the regenerator. Air does not possess the advantage of steam, in being converted by heat, *per saltum*, from a liquid into a gaseous fluid, occupying about 1800 times its former bulk, and of being reconverted, by condensation, into water; but it is simply increased in volume by degrees, in proportion to the heat applied. Therefore, an air-engine, without a regenerator, would be a much less effective and economical application of heat than the steam-engine.

If the correctness of the principle of the regenerator is to be denied, the same objection may with equal truth, be applied to that beautiful apparatus "Jeffrey's respirator," which is an adaptation, although a more recent one, of the same principle; and it might then be asserted that it is of no use to the lungs of invalids, and has no effect in keeping the body warm. The air in passing from the lungs to the atmosphere, gives out a certain portion, but not the whole of its heat, to the metal plates of the respirator, and in being inhaled again takes back the greater part of its heat, and reaches the lungs considerably warmer than the atmosphere, though not so warm as the lungs.

Calling the temperature of the lungs A that of the atmosphere B, that of the inhaled air when it reaches the lungs C, and that of the exhaled air, when it reaches the atmosphere,

D, the difference of temperature, between that of the lungs, and that of the air exhaled, when it reaches the atmosphere, viz., **A—D**, or conversely between that of the atmosphere and that of the air inhaled when it reaches the lungs, or **C—B**, in the case of the respirator, represents what is gained by the regenerator, or economizer of the air-engine.

The difference between the temperature of the air exhaled, when it reaches the atmosphere, and that of the atmosphere viz., **D—B**, or conversely between that of the air inhaled, when it reaches the lungs, and that of the lungs, or **A—C**, in the case of the respirator, represents what is not saved by the regenerator of the air-engine, and which must be made up by the application of heat to the one end of the air-vessel, and of a cooling process at the other, say by cold water led through pipes, as in Stirling's engine, or by the admission of cold air from the atmosphere, as in Ericsson's; the force required to drive the air through the passages, being a farther deduction from the economical process.

The originality of the invention can be best shown by reference to the following extracts from Messrs. Stirling's specifications, and to their dates. It may be here mentioned, that while Dr. Stirling has the merit of the invention of the economizing process, on which the principle of the air-engine is based, to his brother Mr. James Stirling, C.E., is due, the idea of reducing materially the bulk of the engine, by using compressed air, instead of air at the ordinary density of the atmosphere. This improvement was first patented in 1827, and afterwards with farther improvements in 1840.

Extract from Dr. Stirling's specification of an air-engine, patented in November 1816.

"All my improvements for diminishing the consumption of fuel consist of different forms, or modifications of a new method, contrivance, or mechanical arrangement, for heating and cooling liquids, airs, or gases, and other bodies, by the use of which, heat is abstracted from one portion of such liquids, airs, &c., and communicated to another portion with very little loss; so that, in all cases, where a constant succession of heated liquids, airs, &c., is required, the quantity of

fuel necessary to maintain, or supply it, is, by this arrangement, greatly diminished.

The first modification of the said contrivance, is described as follows: "**A B** is a pipe, tube, channel, or passage, formed of

Fig. 1.

metal, stone, bricks, or other suitable materials. The *hot* liquid, gas, or body to be *cooled* is by mechanical, or other means, made to enter the passage at **A**, and to pass along to its other extremity **B**. In its progress, it gives out its heat to the sides of the tube, or passage, or to any bodies contained in it, and issues at **B** at nearly the original temperature of the passage. In this manner, the extremity at **A**, and a considerable portion of the passage, is heated to nearly the same temperature of the hot liquid, air, &c., while the extremity **B** still retains nearly its original temperature.

"When the temperature of the passage, at **B**, has been raised a few degrees, the motion of the liquid, air, &c., from **A** to **B** is stopped, and a portion of liquid, air, &c., which is required to be *heated*, and which is supposed to be a few degrees colder, than the extremity of the passage, at **B**, is made to traverse the same passage, in a contrary direction, *i. e.*, from **B** to **A**, by which means it receives heat from the sides of the passage, or other bodies contained in it, and issues at **A** of nearly the same temperature with the liquid, air, &c., to be *cooled*. When the heat of the passage at **A** has thus been lowered a few degrees, the process is again stopped, and a portion of the liquid, air, &c., to be *cooled* is made to pass from **A** to **B**, and so on alternately."

After describing other modifications of the same contrivance the specification proceeds.

"The form and construction of the tubes and plates, &c., may be varied, according to circumstances, but the benefit to be derived from this arrangement arises from the fluids, airs, &c., to be heated, and those to be cooled, being made to move in opposite directions, &c."

As to the respective merits of Stirling's and Ericsson's engine, it must be admitted, that the former is much more compact in all its parts, and occupies much less space than the latter, owing to the use of compressed air, as already mentioned, which increases the power of the engine almost directly in the ratio of the density of the air, and of course very much reduces the friction of the working parts. The compressing of the air, which is generally from about seven to ten atmospheres, is, in the first instance, necessarily effected by hand, by pumping it into a receiver, or magazine, in the same way as water requires, at the outset, to be pumped into the boiler of a steam-engine. After this, the air is pumped in by the engine itself, and the power required for that purpose is inconsiderable, as it is only the small portion of air which is wanted to make up for leakage, that is required to be supplied, the same air being used over and over again.

In Stirling's engine, the working cylinder being a separate apparatus from the air vessels, and being connected with the cold end of them, is kept quite cool, and thus is free from the objection urged against a former engine of Ericsson's, that it carbonized the oil by its excessive heat.

In an engine of 45 horse-power, which was actually constructed, and was in use for upwards of three years, driving all the lathes and other machinery of the Dundee Foundry,[1] the economizer was composed of slips of the thinnest sheet iron that could be got, 38 inches long, and 1¾ inch broad, placed in the direction of the radii. The passages for the air, between the slips, were about one-fiftieth of an inch in width, and the slips being about the same thickness (one-fiftieth) there would be twenty-five slips in each inch of the circumference of the air vessels. These would expose an aggregate surface of about 460,000 square inches, or 3,200 square feet nearly, to heat and cool the air alternately in each air vessel.

The quantity of compressed air transferred through the economizer, or regenerator, at each stroke of the plunger, was 9 cubic feet nearly, so that for each cubic foot of air, there was an economising surface of $\frac{3200}{9} = 355$ square feet; or, the

[1] Vide Minutes of Proceedings, Inst. C. E., for 1848, vol. iv. page 348.

compressed air being reduced to air of the ordinary density of the atmosphere, would give 9×10 (viz., 10 atmospheres) $= 90$ cubic feet, and $\frac{3200}{90} = 35{\cdot}5$ square feet of surface, for each cubic foot of air of the ordinary density.

Ericsson's wire gauze is stated at 15,000 square feet, and as the supply cylinder sends in nearly 620 cubic feet of air at each stroke, $\frac{15000}{620} = 24$ square feet only of surface, for each cubic foot of air.

As it has been asserted, that Stirling's engine did work effectively and economically for a number of years, it will naturally be asked, for what reason was it abandoned, at the Dundee Foundry? From information furnished by Mr. David Mudie, now one of the lessees of the Foundry, it appears, that the motion of the engine was not perfectly smooth and uniform, which was the only mechanical objection, and that not an important one; but that the real cause of the engine having been set aside, or re-converted into a steam-engine, was, that the bottoms of the air vessels could not be made to withstand the heat to which they were exposed.

The engine of 45 horse-power was started in March 1843. In December 1845, (viz., two years and nine months after starting,) one air vessel gave way; in May 1846, another failed, and in January 1847, a third, when the parties carrying on the Foundry, Mr. Stirling having left the management and gone to Edinburgh, got discouraged by these repeated failures, and removed the engine.

Mr. Stirling has since turned his attention to the best mode of remedying the defects, and there can be little doubt that he could satisfactorily accomplish his object, if he were to meet with support and encouragement, in carrying out and completing his experiments. At present, however, the only active movement being made towards turning this engine to account, seems to be in New York, where certain parties having collected all the information they can procure, as to the patents, and as to the engines constructed at Dundee, are endeavouring to improve Stirling's air-engine, with the intention of bringing it out in preference to Ericsson's.

It remains only to offer a protest, against the use of the

name "caloric engine," as being improper and as leading to misapprehension. Caloric may be a correct enough, although a somewhat pedantic, word for heat, but it by no means signifies heated air, any more than it does heated water, or steam, and a steam-engine is therefore quite as much entitled to the name as an air-engine. That the use of this name does engender a confusion of ideas is certain, and may be shown by reference to paragraphs and advertisements, in American newspapers, in which caloric, as a motive power, is freely spoken of in contradistinction to steam.

The Paper is illustrated by four diagrams, Nos. 4606-7-8 and 9.

No. 896. "On the Conversion of Heat into Mechanical Effect."
By CHARLES WILLIAM SIEMENS, Assoc. Inst. C.E.

THIS subject may be considered under three heads.

First, an inquiry into general qualitative and quantitative relations between heat and mechanical effect.

Second, the theoretical and practical consideration of actual engines, including those of Stirling and Ericsson.

Third, the definition of the characteristics of a perfect engine.

The first portion relates to a purely theoretical question, and would, separately considered, fall beyond the usual limits of discussion at this Institution; but the Author is obliged to ask for an exception in his favour, finding it would be impossible to establish the ultimate object in view, without having proved his premises, which are based upon evidence of recent discoveries.

In discussing the succeeding heads he will have to rely, to a considerable extent, on his individual judgment and experimental researches.

First. On the relations between "Heat and Mechanical Effect."

The power obtained from a steam-engine depends upon the increase of volume given to the water in its transformation into steam, by the action of the fire under the boiler. Dr. Black observed, in 1763, that the effect of the fire was, for the most

part, required to effect the conversion, after the water had been raised to the temperature of the steam itself; and, moreover, that it made no difference whether the evaporation took place in the open air, or in a closed vessel under pressure. Upon these facts he grounded his theory, that steam was a compound of water and heat, which heat, on entering into combination with the water, lost its individual properties, or became latent.

This "material theory" of heat has been generally adopted, in preference to the "theory of undulation," according to which heat is regarded to be the undulatory motion of a supposed ætherial fluid pervading all nature.

The supporters of the material theory explain the different phenomena of sensible, radial, and latent heat, by the free, or combined state of their supposed fluids; the "specific heat of bodies by their different degrees of affinity for that fluid." The affinity of materials for heat is supposed to be invariably increased by increase of volume, and the evolution of heat, by friction between solids, is supposed to arise from permanent compression of their particles.

The latter supposition has been disproved by Sir Humphry Davy, who showed, that heat was evolved by friction between two pieces of ice, which caused them to melt, and could not, therefore, arise from permanent compression of the solid particles.

Dulong proved, moreover, that the specific heat of gases is the same before and after compression, showing that the heat lost in their expansion is not absorbed into the gas, and cannot be accounted for according to the "material theory." Joule, of Manchester, produced heat by agitating water in a closed vessel, and also by an electric current, which, in its turn, was produced by power, in turning the handle of a magneto-electric machine.

The latter experiments are not only proofs against the supposition that heat is material; but their greater value consists in showing an intimate connection between heat and the mechanical force by which it was produced, and they are the foundation of the "dynamical theory of heat."

According to this theory, in its general form, heat, mechanical force, electricity, chemical affinity, light, and sound, are but different manifestations of one great and infinite cause—"motion."

Recent discoveries and experimental researches all accord

with this great principle, which seems destined to open a new era of natural sciences.[1] Dulong and Gay-Lussac have proved, by their experiments on sound, that the greater the specific heat of a gas the more rapid are its atomic vibrations. Elevation of temperature does not alter the rapidity, but increases the length of those vibrations, and in consequence produces "expansion" of the body.

The specific heat and temperature of a body determine the vibrating velocity of the material particles, the square of which, multiplied by the weight of the particles, gives their inherent force, or "vis viva."

In solids the "vis viva" is least remarkable, in fluids it is greater, and in gaseous fluids it predominates so strongly over the gravitation, that the latter force becomes practically inappreciable.

Joule explains the elastic pressure of a gas, by the rebound of its particles against the sides of the vessel containing it,[2] and proves the correctness of his views by calculation. If one side of a vessel gradually yields to the pressure, as is the case with a working piston, then the rebound of the particles will be less than their impact, and consequently the length of their vibrations must diminish, in proportion to the outward motion produced.

It is thus shown, that vibratory motion, or heat, is converted into its equivalent of onward motion, or dynamical effect.

To express this equivalent by number, it is necessary to agree, in the first place, on an arbitrary unit of heat, which is usually the heat required to raise the temperature of 1 lb. of water through 1° Centigrade, or Fahrenheit, and also, on a unit of mechanical effect, which is usually the "foot-pound," or the power required to lift 1 lb. through 1 foot. The data for these calculations may be taken from any materials, the specific heat and density of which are well known.

The nature of the material cannot effect the result, for if one should be more favourable to the production of mechanical force by heat, than another, and the second be more favourable to the reverse process, it would follow that by a judicious selection of materials, a machine might be devised, which would reproduce more than its own cause of motion. This would be "to

[1] Vide Grove "On the Co-relation of Physical Forces," 1842 and 1850.

[2] Vide "Transactions of Philosophical Society of Manchester," 1848.

ascribe creative power to matter," in contradiction to the laws of nature.

The limits of this paper do not permit of the train of reasoning, by which the numerical equivalent of power for heat has been ascertained, in different ways, by English, French, and German natural philosophers, within the last ten years; the Author must, therefore, content himself with merely mentioning their names and publications. Carnot and Clapeyron produced the first general formulæ, which contained, however, an uncertain function, and were still based upon the supposition that heat was material.[1] Holtzman, of Manheim, in pursuing the views of Carnot and Clapeyron, obtained a complete mathematical solution in 1845.[2] Joule, of Manchester, solved the problem experimentally about the same time.[3]

The "dynamical theory" was more fully developed by Helmholtz in 1847,[4] and Mayer.[5] Mr. W. J. M. Rankine, C.E., and Professor Thompson, of Edinburgh, have much extended the dynamical theory of heat, and applied the same to calculate the power of steam and air engines.[6]

M. Regnault, of Paris, has, by careful experimental researches on the total heat of steam, &c.,[7] provided some important data for the development of the dynamical theory of heat.

The following are the results obtained in units of power, or foot-lbs., for one unit of heat, by different authors:—

	Centigrade Thermometer.	Fahrenheit's Thermometer.
By Holtzman's formula	1227 foot lbs.	682 foot lbs.
By Joule's experiments	1386 ,,	770 ,,
By Rankine's formula	1252 ,,	695 ,,
By Thompson's formula	1390 ,,	772 ,,
For the best Cornish engine, by M. de Pambour	148 ,,	82 ,,
For a perfect low-pressure condensing engine	90·8 ,,	50·4 ,,
For an actual Boulton and Watt's engine	46 ,,	25·5 ,,

[1] Vide Ann. de Chem. et Phil., XXIII.

[2] Vide his pamphlet "Ueber die Waerme und Elasticitact der Gase und Daempfe."

[3] Vide "Transactions of the Philosophical Society of Manchester," Vol. 18.

[4] Vide Ueber die Erhaltung der Kraft.

[5] Vide Mechanische Aequivalent der Waerme, 1851.

[6] Vide "Transactions of Royal Society of Edinburgh," 1849 to 1850 and 1850 to 1851.

[7] Vide Comptes Rendues.

The comparatively small effect produced by the steam-engine of the present day would seem to indicate that there is still much room for improvement.

Practical Engineers will probably receive with incredulity, and certainly derive but little advantage from, the preceding numerical statement, the result of abstract calculation, unless it can be proved by simple demonstration, and in such a manner that the essential difference between the actually and the theoretically perfect engine is clearly pointed out.

The Author proposes to accomplish this by means of a diagram (Fig. 1, Plate 3), which is, in effect, the expansion curve of saturated steam indefinitely prolonged.

The vertical lines and figures at the bottom signify the pressures of saturated steam in lbs. per inch; the horizon al lines and figures on the sides denote the volume of steam compared with the volume of water, from which it is produced; and the horizontal lines, with figures on the curve, express the temperatures of the steam corresponding to the pressure and volume of the same.

The outer curve, *a a a*, is that usually employed in calculating the power of expansion engines, being the expression of Watt's law "that the total heat in steam is the same at all pressures."

The inner curve, *b b b*, is the corrected one, in accordance with the recent discoveries of Regnault, "on the total heat of steam,"[1] and may be termed "the curve of equal heat."

The fields between the horizontal dotted lines represent the power given out by the steam, in losing equal decrements of 10° of temperature in its expansion, and it is important to observe, that the areas of these fields are nearly alike, between the limits to which the pressure and temperature of steam are experimentally known, increasing only slightly, and in a uniform ratio inversely as the temperatures.

This gradual increase may be ascribed to the fact, that the curve in question is one of equal heat, whereas it has been shown, that in expanding behind a working piston, the steam must lose heat in the dynamical proportion to the power given out.

---

[1] Vide "The Publications of the Cavendish Society," Vol. I.

Messrs. Rankine and Clausens have first drawn attention to this circumstance, and proved that the expansion of steam, behind a piston, must be attended by partial condensation.

On the other hand, experiments made by the Author [1] prove that steam, when expanded spontaneously, is superheated steam, being a verification of Regnault's discovery, that the total heat of steam increases with its pressure.

When steam is expanded behind a working piston the excess of free heat is first absorbed, or changed into dynamical effect, and if that does not suffice, partial condensation must take place. It appears, however, to the Author, that Messrs. Rankine and Clausens undervalue the amount of free heat, and, therefore, over estimate the amount of condensation during expansion, by taking the specific heat of steam at 0·305 (Regnault's coefficient of increasing heat), which there seems good reasons to believe is far too low, because:—

1st. The specific heat of an elastic fluid must be proportionate to its rate of expansion by heat. It has been shown, however, in experiments instituted by the Author above referred to, that the rate of expansion of steam near its point of saturation, is about three times greater, than that of air at the same temperature, which would make its specific heat $3 \times \cdot 267 = \cdot 801$, diminishing however rapidly with the increase of temperature.

2nd. The actual forms of diagrams, taken from the best expansive steam engines, do not show the effect of condensation: the ordinates of the lower portion of the curve are indeed higher than those given by Watt's law, starting from the same point. This is shown by Fig. 2, Plate 3, which is a diagram taken from the Old Ford Engine, by Mr. W. Pole,[2] in which *a a a* is the actual curve, *b b b* the curve representing Watt's law, and *c c c* the curve of equal heat. The rise of the actual curve toward the end, may in part be owing to the generation of steam from the heated sides of the cylinders; but it could not be supposed, that the effect of such generation would equal that of spontaneous condensation throughout the body of the steam. Moreover the actual curve proves to be almost the perfect dynamical curve, as is proved by the equal areas, or fields of

[1] Vide "Transactions of the Institution of Mechanical Engineers," for June 1, 1852.

[2] Vide "Treatise on the Cornish Engine," by W. Pole, Part III.

power, obtained by drawing lines from points of the curve of equal progression of temperature. If the limits of the sheet of diagrams had admitted of a continuation of the curve horizontally, (Fig. 1, Plate 3,) it would have exhibited continually decreasing volumes, and increasing temperatures, until finally a point would have been reached, where the volume of the steam was equal only to the water producing it. It may be assumed, that the temperature would, at that point, be 640° Centigrade (1180° Faht.), or in other words, that the entire heat of the steam would be sensible. Supposing this steam (which would have at least 2000 lbs. pressure per square inch) could be introduced below a piston, and in giving out its power be expanded, until its temperature was reduced to zero; then the entire 640 degrees of heat, would have been converted into their equivalent of power, of which the field of the diagram would represent the integral. The theoretical equivalent of mechanical force for heat is thus represented to the eye; and in computing the area of the entire figure, it is found to coincide nearly with, but somewhat to exceed, the results of abstract calculation and of Mr. Joule's experiments. That portion of the diagram (Fig. 1) which is shaded darker than the rest, represents the power of a perfect low-pressure condensing engine; it covers only about 1-14th part of the entire area.

The diagram shows, that the expansive steam-engine would be theoretically a perfect engine, if the water was heated in a close boiler, to 1180° Faht., and being then introduced below the working piston, under a pressure of at least 2000 lbs., would resolve itself entirely into steam, and was allowed to expand 2000 times, before it was discharged into a vacuous space, which, in this case, would not necessarily be a condenser. The impracticable nature of such an engine is manifest, and it becomes necessary to seek for other means of obtaining from heat its full value of power.

It may not be considered out of place to mention here, the well-known experiments on steam guns by Mr. Perkins, which went far to prove the actual possibility of charging water with sufficient heat, in close vessels, that, upon liberation, it would resolve itself entirely into steam.

Before leaving this part of the Paper, it will be necessary to

show the effect produced by the expansion of air, or any other permanently elastic fluid, under a working piston. In the diagram (Fig. 3, Plate 3), the figures on the base and vertical lines denote the pressures in lbs. per square inch, and the figures on the side denote volumes of steam, as compared with the volume of the same weight of water. The curve *a a a* represents Marriotte's law, and is a curve of equal heat. The curve *b b b* is the dynamical curve, representing the real rate of expansion of air, behind a working piston. The difference between the two curves arises from the loss of sensible heat, which is converted into effect. The figures upon the curve show the rate of progression of temperature, in compressing air of atmospheric pressure at 60° Faht.

In constructing this curve, the specific heat of air at constant volume, has been taken at ·267 as determined by Delaroche and Bernard. It furnishes itself at least an approximate proof of the correctness of this number, because the curve agrees with the observed fact, that in compressing air, to double its original pressure, its temperature is raised 70° Faht. The dotted horizontal lines limit the uniform fields of power obtained for every 10° decrease of temperature. This curve is directly applicable to air, which when reduced to atmospheric pressure, has a temperature of 60° Faht. It can, however, easily be corrected, for any degree of temperature, by adding the difference of temperature, at a corresponding pressure throughout, and by adding to each volume, the same difference of temperature, divided by 508 (the ratio of expansion of air at 60° Faht.)[1]

[1] The dynamical theory of heat must not be considered the creation of the last few years, but, like all abstract truths in nature, it seems to have presented itself to the minds of the greatest philosophers in all ages, to be, after them, again superseded by theories moulded, as it were to order, to explain some isolated phenomenon, such as the radiation of the sun, the heating flame of a fire, or the latent heat in steam; until at length the means of observation were sufficiently perfected to cover with absolute proof, what could before be reached only by the imagination. It may here be mentioned, as instances, a quotation by Baron Humboldt from Aristotle, "who considered the first principle in nature to be a unity in all its manifestations, and the manifestations themselves he reduced always to motion as their foundation." Again, in Lord Bacon's Aphorisms, the chapter on "The first Vintages of the Force of Heat," occurs the following remarkable passage:—"From the instances taken collectively, as well as singly, the nature whose limit is heat, appears to be motion." And

Secondly.—"On the performance of actual engines, including the air-engines of Stirling and Ericsson."

In accordance with the principles put forth, the power of an engine is expressed by a simple formula:

$$\text{1st. Ind. H.P.} = \frac{a\,c}{33{,}000}\left(r p - p' + \frac{r\,A(t-t')}{v}\right.$$

in which c is the velocity of the piston in feet per minute; a the area of the same in square inches; t the temperature of the steam, or air, on entering the cylinder; t' its temperature on leaving the same; v expresses the volumes of the steam, or air, on entering the cylinder, as compared to one volume of water; r the ratio of expansion, or fraction of stroke at which the supply is shut off; A a constant, denoting the mechanical equivalent, per unit of heat, being (as shown by the diagrams) for steam = 400, and for air = 0·267 × 400 = 106; p the pressure of the fluid on entering the cylinder (pressure in boiler) in lbs. per square inch; and p' the pressure against the working piston (back pressure) in lbs. per square inch.

The power required to work air, or feed pumps, has to be deducted from the result of this formula.

Take, for example, an expansive and condensing steam-engine of 16 inches diameter and 200 feet velocity of piston; the total pressure of steam in the boiler 60 lbs., cut off at one-fourth part of the stroke; the vacuum in the cylinder averaging 11 lbs. (having 4 lbs. resisting pressure); the initial temperature of the steam = 295°; and the final temperature t' = 207° Faht.; the volume at 60 lbs. pressure would be = 460° (see diagram, or any table on the pressure, temperature, and volume of steam).

The indicated H. P. of this engine will be

$$= \frac{201 \times 200}{33{,}000}\left(0·25 \times 60 - 4 + \frac{0·25 \times 400\ (295 - 207)}{460}\right) = 36·75.$$

The evaporation in the boiler is $2\ \dfrac{r\,a\,c}{2·4\ v}$ = 9·1 cubic feet of water per hour.

---

further on,—"But that the very essence of heat, or the substantial self of heat, is motion, and nothing else limited," &c. &c. Bacon fails, however, in his attempts to prove his philosophy, in confounding the visible motion of heating water, or of fire, with the intrinsic motion of the particles that manifests itself as heat.

The result agrees with that obtained by the usual method of computing the contents of the expansion curve, and is certainly more accurate and more expeditiously arrived at.

For non-expansive engines, the factor $\frac{r\,A\,(t - t')}{v}$ has no value, because $t = t'$, and $r = 1$.

In applying this formula, to ascertain the power of an air-engine, the value of the constant A is = 106, as shown by the diagram, Fig. 3, Plate 3.

If the object is to ascertain merely the relative economy of an engine, as compared with a perfect engine, it suffices to determine—

1st. The total units of heat which are imparted to the working fluid, and, 2nd, the units of heat which disappear in producing useful effect; and inasmuch as the former exceed the latter, so the engine falls short of producing a full equivalent of mechanical effect for the heat expanded.

Take the example of an air-engine consisting of a working cylinder A, an air-pump B, and a reservoir D between them (Fig. 4, Plate 3). To obtain the greatest effect, the admission of air into the working cylinder should, under all circumstances, be so regulated, that it may expand down to atmospheric pressure before it is discharged.

Supposing that nothing was known of the proportion between the cylinders, of the working pressure, nor of the rate of expansion, but that the temperature of the air was known to be,—

60° Faht. On entering the pump at *m*.

130° „ On entering the vessel D, which would be the case if compressed to half its original volume.

710° „ On entering the working cylinder, which would be the heat required to double its volume at constant pressure, and

570° „ On being discharged, having lost 140° in its expansion down to the atmospheric pressure.

Then the heat supplied by the fire would be = 710 – 130 = 580° Faht. and the difference of temperature of the air, on entering and on leaving the engine, would be = 570 – 60 = 510° Faht. It follows, that 580 – 510 = 70° of heat have been converted into their equivalent of mechanical effect, and

the duty performed by the engine, for every one unit (Faht.) of heat employed, is $= \frac{70}{580} 770 = 91{\cdot}2$ lbs. lifted 1 foot high.

The expansive air-engine is, therefore, theoretically superior to Boulton and Watt's condensing engine, but inferior to a good expansive engine. Practically considered it is certainly inferior to both, because one-half of the gross power of the working piston is absorbed by the pump, and the losses by friction and leakage are trebled in consequence. Moreover, it has been found by its earliest promoter, Mr. Stirling, of Dundee, that the working of a tight piston, in a highly-heated cylinder, is attended with almost insurmountable difficulty.

The most essential difference between the steam-engine and the air-engine is, that in the former, the unproductive heat is expended in the boiler, where it becomes latent, in effecting increase of volume without displacement of the piston, whereas in the latter, it presents itself as free heat at the exhaust port.

Mr. Stirling, and after him Captain Ericsson, in taking advantage of this circumstance in favour of the air-engine, employed the free lost heat to warm the fresh air on entering the reservoir from the pump.

Ericsson constructed an engine on this plan, in 1833, which, according to received accounts, worked with considerable economy of fuel, but failed, in consequence of a defective heating apparatus, and the continual derangement of the working piston in a heated cylinder.

The apparatus he employed for recovering the lost heat resembled a locomotive boiler, through the tubes of which the cold air passed, while the heated and expanded air circulated in the opposite direction, through the intervening spaces. He termed this apparatus, the "regenerator," because he supposed, that by its means the same heat might be used perpetually over and over again, to produce motive power.

Stirling, of Dundee, patented an air-engine in 1816, and improvements in 1827 and in 1840. He constructed one of these machines, an account of which he brought before the Institution in 1845.[1] In it he had combined several important advantages over former attempts, namely—

1st. The hot working piston was dispensed with.

---

[1] Vide "Minutes of Proceedings, Inst. C.E. for 1845," vol. iv., p. 348.

2nd. The working pressure was increased, by using the same body of highly-compressed air over and over again.

3rd. The reabsorption of the waste heat was carried out to greater perfection, by means of a series of thin iron plates, presenting a very large aggregate surface, which were held a small distance apart by fillets, to allow of the passage of air between them.

The lower extremities of these plates were heated by the fire to about 650° Faht., while the upper extremities were maintained at the lowest possible temperature, by coils of cold-water pipes. The air was made to pass to and fro between the same surfaces, for every stroke of the engine, by means of a large displacing plunger, which was not required to work tight in its cylinder. In descending, the air absorbed heat, in the gradual proportion of the increasing temperature of the plates, and in consequence its elastic pressure was increased during the ascending stroke. By the reverse process, a fall to the former temperature and a decrease of pressure, inversely proportionate to the temperature and the space occupied, was effected, which space was, in the meantime, increased by the amount of the capacity of the working cylinder.

The opposite ends of the working cylinder communicated with two distinct heating apparatuses, the displacing plungers of which were attached to the opposite ends of a beam and made stroke, while the working piston was on its dead centres.

The excessive pressure of the heated air, beneath the one, over the cold air above the other displacing plunger, constituted the working pressure; and the capacities of the displacing cylinders had to be so proportioned to the working cylinder, that the working pressure was not exceeded by the resisting pressures at the end of each stroke; or supposing the volume of the air was doubled by the heat, it follows, that the net capacity of each displacing cylinder had to be equal to at least twice the capacity of the working cylinder.

Fig. 5, Plate 3, is a theoretical diagram of Stirling's engine; the curve *a a a* represents the entire expansion of the air, from the time when it is all confined in the heated space, below the displacing plunger, to the moment when it occupies the cold extended space, above the displacing plunger, and the working cylinder. The power due to this expansion is measured by the

field *a a a x y z*, and is equivalent to 123 units of heat, as shown by (Fig. 3, Plate 3); whereas the power actually imparted to the working piston is represented by the portion of the diagram marked *b b b*, the corners of which are rounded off, in the ratio produced by the two cranks working over right angles, and is equivalent to 27·5 units, being about $\frac{2}{9}$th parts of the entire area. The field *b b b y z*, immediately below the sectioned portion, represents the back pressure on the working piston, or the power required to force the air from the working cylinders back into the displacing vessels.

The theoretical effect produced by a Stirling's engine, is to that of a perfect engine, as the units of heat expended in the entire expansion to the units producing useful effect, or as 123 to 27·5.

There remains to be considered the necessary mechanical loss of heat, owing to the difference of temperature between the air on entering the cool ends of the metallic plates, (the regenerators) and on returning from the same, which loss has been proved, by experiments hereafter to be explained, to amount to about 25° Faht., or to $\frac{3}{4} \times 25 = 19°$ Faht., if distributed upon the entire quantity of air employed, because only three-quarters of the same are actually heated each time.

The real effect of a Stirling's engine, as compared with a perfect engine, is therefore as $123 + 19 \div 27{\cdot}5 = 5{\cdot}16:1$, or it yields the power of $\frac{770}{5 \cdot 16} = 130$ lbs. lifted 1 foot high, for every water unit of heat expended.

It follows from the above, that the Stirling's engine converts into dynamical effect about one-fifth of the heat supplied, which is about equal to the performance of the best Cornish engines.

For calculating the actual power of a Stirling's engine of given proportions, the formula assumes the following more simple form :—

3. Ind. H.P. $= \frac{a\ c}{33{,}000} \times \frac{A\ (t - t')}{5 \cdot 16\ v}$ in which $A = 106$ and $t - t'$ the decrease of temperature, by the expansion of the air from the greatest to the lowest pressure.

The cause of the failure of Mr. Stirling's engine in practice, may apparently be traced, chiefly to insufficiency of heating surface, occasioned apparently from misapprehension of the

principle involved, it having been thought, that the same heat would serve over and over again to produce power, and that the necessary expenditure of heat consisted only in the mechanical loss by imperfect action of the respirative plates, which were approached to each other to the utmost limits, consistent with an unobstructed passage of the air.

By the aid of the dynamical theory of heat it has been shown, that there is another and far more important expenditure of heat, which should have been provided for.

Another great practical defect in Stirling's engine, arises from the necessity of providing a reservoir of highly-compressed air to start with, and from the difficulty of preventing the escape of that stock of air, through the stuffing-boxes, &c.

Ericsson patented in 1851 another form of engine, which has lately been executed on a gigantic scale and continues to excite public attention.

This engine, of which (Fig. 6, Plate 3), represents the theoretical diagram, differs from the expansive air-engine (Fig. 4, Plate 3), only in the application to it of Stirling's respirator, or regenerator, and in the proportion between the capacities of the working and pumping cylinder, which in his engine are as three to two. *A* is the working cylinder, the bottom of which is made of wrought iron, and exposed to the fire; *B* is the pumping cylinder, which draws in atmospheric air through the valve *u* and delivers it into the air reservoir *C* through the valve *v*; *D* is a slide valve, regulating the admission of air to and from the working cylinders; *E* is the respirator, or regenerator (a box filled with wire gauze), which is heated at the bottom by the fire, but is maintained cool towards the upper end, by the alternate rush of cold air downwards. The top of the working cylinder and the bottom of the pumping cylinder are left open to the atmosphere, and the two pistons are attached to the same rod by which motion is imparted to the crank.

The pressure in the air reservoir *C* is said to be maintained at 10 lbs. per superficial inch (= 25 lbs. total pressure). In the diagram, the figure *a b c d e* represents the entire pressure below the working piston amounting to 28 lbs. pressure per inch, up to the point *c*, where the admission is supposed to be cut off, in order to expand the air down to atmospheric pres-

sure, before it is discharged, whereby the maximum effect will be obtained. From this gross effect has to be deducted, first the resisting pressure of the atmosphere against the working piston, which is represented by the field *a b f e*, and secondly the power absorbed by the pumping cylinder *B*, as represented by the field *b g h f*. By laying this field of resistance upon the field of power *b c d f* of the working cylinder, there remains the field *b c d h g* representing the entire effective pressure upon the working piston. This pressure amounts, on the average, to nearly 3 lbs. per square inch on the working piston.

In order to estimate the comparative economy of Ericsson's engine, it is necessary to consider the total quantity of heat absorbed for one revolution, the proportion of it which is transferred into useful effect, and the difference between the two, which, of necessity, escapes in the form of sensible heat.

If the atmospheric air enters the pumping cylinder at a temperature of 60° Faht., it will be raised, by compression, to 10 lbs. additional pressure and to a temperature of 111° Faht., as is shown in the dynamical diagram (Fig. 3, Plate 3).

This air has to be heated on its passage to the working cylinder, so that its volume is increased in the proportion of two to three, in order that the air delivered by the pumping cylinder may each time suffice to fill the working cylinder. To effect this it must be heated to 391° Faht.

The expansion that takes place in the working cylinder, will reduce that temperature to 314°, which is the temperature at which the pumping cylinder full of air at 60° will fill the working cylinder of one-half greater capacity (for $\frac{508}{2} + 60 = 314$).

The temperature lost, during expansion in the working cylinder, is $391 - 314 = 77°$, which must be supplied to it again by the fire, before it reaches the respirator, in order not to cool down its lower extremity, and 25° in addition, to make up for the loss, on account of the imperfect action of the same.

The air issues into the atmosphere at a temperature 25° above that of the upper extremity of the respirator, or at $111 + 25 = 136°$ Faht., being $136 - 60 = 76°$ hotter than when it entered.

Therefore—

The total heat supplied to the air	= 77 + 25 =	102° Faht.	
The sensible heat carried off	= 136 − 60 =	76	,,

There remains the heat absorbed by being converted into effect . . . . 26° Faht.

Or the Ericsson engine produces the effect of $\frac{26}{102}$ 770 = 196 lbs. lifted 1 foot high, for every (water) unit of heat expended.

This proves, that the Ericsson engine realises, theoretically, nearly one-third the effect of a perfect engine, and would possess a considerable advantage over any of those before considered, but for the following serious imperfections:—

1st. Its gross working pressure has been demonstrated to be 3 lbs. per square inch, but the engine being single-acting, the true average pressure is only $1\frac{1}{2}$ lb. per inch, and supposing the engine will move with $\frac{1}{2}$ lb. pressure per inch upon the working piston, its mere friction will absorb one-third of the whole power.

2nd. The working piston has to move air-tight in a heated cylinder, which by former attempts has been proved to be attended with great practical difficulties. These are no doubt reduced, by the air being heated in a smaller degree than had been attempted before; but the temperature still remains sufficient to carbonise the lubricating material, and by affecting the shape of the cylinder, to cause leakage.

3rd. The available heating surface of the engine is confined to the bottom surface of the working cylinder, and to the passage leading to the regenerator.

Taking into account the intermittent action and slow heat-absorbing power of the air, the heating surface of an air-engine should, in the opinion of the Author, not be less than 6 superficial feet for 1 lb. of coal consumed per hour, or about seven times larger than in the engines of the "Ericsson."

4th. The weight, bulk, and first cost of Ericsson's engine are inversely proportionate to its low working pressure and slow speed

5th. Incidental losses of heat, by radiation from the large exposed surface of the heated cylinder, necessitate a very considerable addition to the expenditure of fuel.

The engines of the "Ericsson" are said to consist of four working cylinders of 14 feet diameter and 6-feet stroke, making upwards of 14 strokes per minute.

Their collective indicated H.P. is $\frac{4 \times 21168 \times 84 \times 3}{33000} = 676$, from which must be deducted 33 per cent. for friction of pistons alone, and say 27 per cent. for friction of general machinery and of the air in rushing through the regenerator; in all 60 per cent., leaving 271 actual H. P.

There still remains one distinct class of engine for consideration, namely, the combined Steam and Ether engine. This consists of an ordinary steam-engine with a tubular condenser. Instead of the cold water, which is usually admitted into the chamber surrounding the tubes, ether, or chloroform, is substituted, which, it is well known, boil at a temperature far below the boiling-point of water, and therefore will generate their own vapours, under a considerable pressure, by the heat given off by the steam in the act of condensation. The vapours of ether, or chloroform, are made to give motion to a second engine, and are in their turn condensed by very cold water.

It would seem, at first sight, that by this ingenious arrangement the power obtained for a given quantity of fuel was doubled, if compared with the performance of the steam-engine alone; but the preceding investigations will have proved, that the heat imparted to the ether must fall short of that given out under the steam-boiler, in proportion as the heat is changed into the dynamic effect obtained from the steam-engine. The additional effect of the ether-engine might indeed be obtained at once from the steam, if the expansive action of the steam was sufficiently extended; considering, however that an engine, in which the steam is expanded at one-third part of the stroke, absorbs only about one-eighth portion of the entire heat of the steam, and considering also that it is very inconvenient to extend the rate of expansion much further, in rotary engines, there remains, at present, a considerable advantage in favour of the combined steam and ether engine, if the practical difficulties involved, such as the tightness of the joints, are not taken into account. Supposing the dynamic equivalent, per unit of heat obtained by the engine, to be 90 foot-lbs., that of the ether-engine may be taken at two-thirds, or 60 foot-lbs., making a

total of 150 foot-lbs.,—which nearly equals the performance of the best Cornish engines.

The following table is intended to convey a more distinct idea of the comparative merits of the different steam and air engines referred to.

Description of Engine.	Theoretical Performance in Foot-lbs.	Actual Performance in Foot-lbs.	Actual Performance in lbs. of Coal per H. P. per Hour.
A Boulton and Watt condensing engine, low pressure . . .	51·8	29·	8·00
The best Cornish engine . . .	158·8	82·	2·38
Combined steam and expansive ether engine	150·0	75·	3·09
The expansive air-engine . .	91·0	35·	6·63
Stirling's engine	130·0	65·	3·57
Ericsson's engine	196·0	65·	3·57
A perfect engine	770·0	385·	0·60

The statements of the actual performance of air-engines must be considered as only rough approximations, as it is not possible to calculate losses of heat, with any degree of precision. The actual performance of the "Ericsson" engine may be deemed too low, considering its theoretical superiority; but the Author considers the disproportion to be fully accounted for, by the extraordinary losses of useful effect, arising from the exposure of the heated cylinder, and the low working pressure.

In Stirling's engine, the heated cylinder is closed and surrounded by flues and brickwork, in consequence of which, its economical effect is thought to be equal to that of Ericsson's engine, although it is in theory inferior.

Third. On the necessary characteristics of a perfect engine.

In the first part of this Paper it has been shown, that an engine would be theoretically perfect, if all the heat applied to the elastic medium was consumed in its extension behind a working piston, (or its substitutes, such as a disc, a flexible bag, &c.) leaving no portion of it to be thrown into a condenser, or into the atmosphere. In the second part, several actual engines have been examined, with a view to test their degree of theoretical and practical perfection. Such an inquiry should have

for its end, the attainment of some more perfect result than could hitherto be obtained. The Author will therefore attempt to state his views of the characteristics of a perfect engine.

1st. All the elastic material employed should actually enter the working cylinder, (or its substitute,) and produce its full value of effective displacement of piston, without deduction for the resisting pressure, or the working of pumps.

2nd. The production of the elastic material, previous to its entering the working cylinder, should not require a continuous expenditure of heat, or in the case of the steam-engine, the latent heat expended in the boiler should be recovered.

3rd. That working material is the best which is capable of receiving the largest possible quantity of heat in a given space. Its temperature and pressure should be raised to the highest point which the vessel containing it will admit of, but on leaving the working cylinder, the temperature should be reduced to a minimum. This may be accomplished, either by infinite expansion, or practically by the application of a regenerator.

4th. Losses of heat by radiation and leakage, should be reduced to the smallest possible amount, by working at high pressure and velocity, and by covering all heated surfaces with non-conducting materials. These losses being, proportionally, more to be apprehended in a perfect, than in an imperfect engine.

5th. Large and compact heating surface and considerable body of material are essential, to attain a high temperature, without rapid destruction of the vessels.

6th. No working part of the engine should be brought into contact with highly-heated material.

The respirator, or regenerator, is undoubtedly a useful agent, for recovering the free, or otherwise unproductive heat of a caloric engine, and the following experimental investigations on its action, by the Author, may not be thought devoid of interest.

The annular space between two concentric cylinders was fitted with 750 brass strips, each 5 feet 9 inches long, and held $\frac{1}{16}$th of an inch apart from each other, by projecting ribs upon every alternate strip. The internal cylinder contained a piston, with an enlarged hollow piston rod, passing through a stuffing-box, and was worked to and fro by an engine. The lower

extremity of the external cylinder was heated by a fire to 650° Faht., as indicated by the pyrometer, and was maintained at that temperature.

A second, or charging cylinder was provided, which by the motion of its working piston, alternately withdrew and returned the same air to the first cylinder. The capacity of the charging cylinder was 24 cubic feet, and its piston made 18 strokes per minute: about two-thirds of its contents, or 16 cubic feet of air of atmospheric pressure, passed with each stroke, to and fro through the respirator, and all the heat carried away was absorbed by the sides of the cylinder. After 2½ hours' working, the temperature of the charging cylinder was raised from 60° to 110° Faht. (50°). Its capacity for heat had been previously ascertained, by suddenly admitting steam, and weighing the condensed water obtained (in heating it from 60° to 210° Faht.) (150°), which amounted to about 54 lbs. The quantity of air which passed from the respirator into the cylinder was 43,200 cubic feet, and its weight 3360 lbs.: this, if multiplied by its specific heat 0·267, is equal to 897 lbs. of water-power of absorbing heat. The heat given off was $\frac{50}{150}$ 1000 = 18000 units, and consequently the air left the respirator, each time, at a temperature of $\frac{18000}{897} = 20{\cdot}01°$ higher than that at which it entered. Adding to this, for loss of heat by radiation during the experiment, which according to established rules may be taken at 5°, the entire loss of heat by the respirator amounts to 25° Faht. when air is employed. In using steam it does not exceed 10° Faht., owing to the greater conducting power of that fluid.

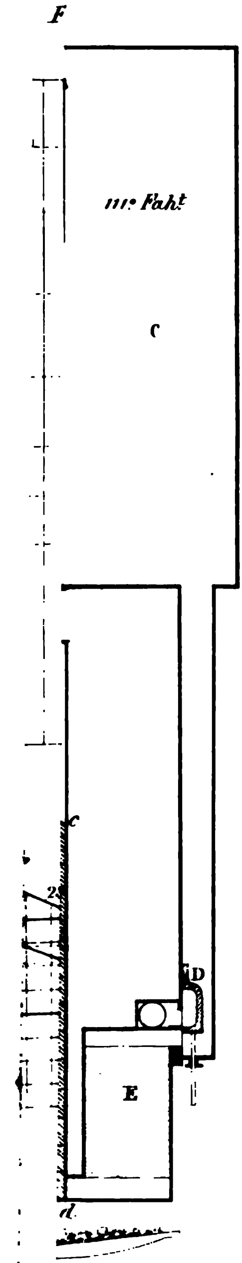
The regenerator condenser, which was designed and executed some years ago by the Author, is an illustration that water may be also subjected to respirative action.

The Paper is illustrated by a series of diagrams from whence Plate 3 is compiled.

[Mr. C. Manby

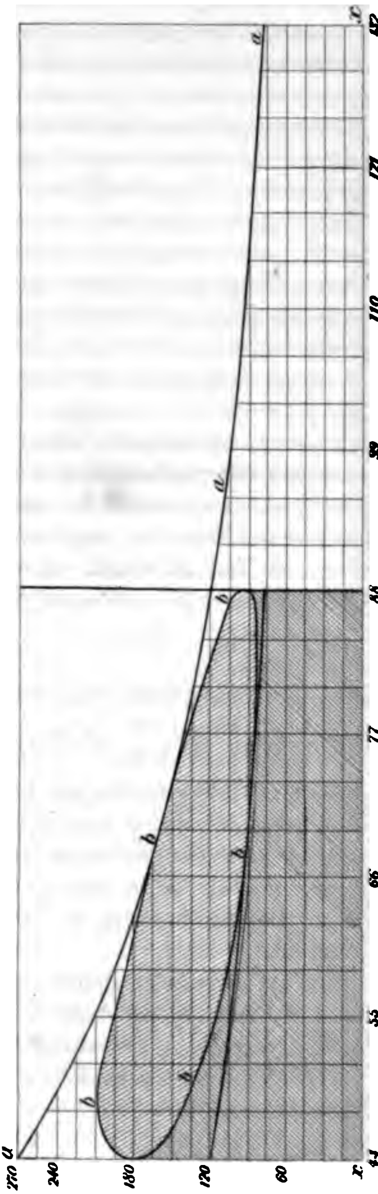
FO E.

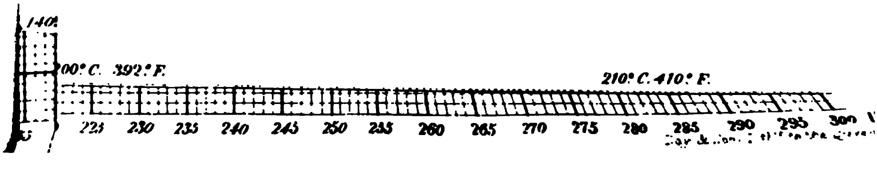
F



STIRLING'S ENGINE.

Fig. 5.





Mr. C. MANBY, Secretary, read some quotations from a letter addressed by M. Regnault to Colonel Sabine, Treas. Royal Society, (dated April 1853), in which he stated, that he was about to publish, immediately, a series of elaborate experimental researches, on various subjects connected with the effects of heat on elastic fluids; the results of which would solve many questions long in dispute, and by means of which engineers might accurately calculate the effect of a given amount of fuel, in whatever way it was applied. M. Regnault communicated in anticipation, that he had arrived at the number 0·237, for the specific heat of air, at constant pressure, and at 0·475, for that of steam, under atmospheric elasticity, the specific heat of water being taken in each case as unity.

Mr. SIEMENS explained, that the diagrams were chiefly intended to illustrate the peculiar functions of the "respirator," or as Mr. Ericsson had termed it, the "regenerator." Very conflicting opinions had been expressed regarding this most essential element in Ericsson's engine. Some thought that, by its agency, the heat used to effect a stroke of the engine could be wholly recovered, except accidental losses, and that, theoretically, it involved the accomplishment of a perpetual motion. Others, on the contrary, contended that the regenerator was only an obstruction to the passage of the air, and of no utility whatever. He had endeavoured to prove in his Paper, that neither the one extreme view, nor the other was correct; that, indeed, the respirator might be usefully employed, to recover that portion of heat which presented itself at the exhaust part of the engine, in the form of free, or sensible heat, but that neither the respirator, nor any other possible contrivance, could recover the heat that was lost in the expansion of the air behind the working piston. He had adopted the new "dynamical theory of heat" for his argument, because that theory enabled him to calculate the absolute quantities of heat, that must inevitably be sacrificed, to produce a given mechanical effect, and to separate the same from the other and much larger quantity, that served only to form the elastic medium behind the working piston, and which might be recovered, by means of a respirator, unless, as he had shown in the Paper, it was all converted into power, by the expansive action being carried to its last (but impracticable) limits. Ericsson himself seemed to incline to the idea, that he

could recover the whole of the heat by means of his "regenerator," for it would be difficult otherwise to account for the extraordinary insufficiency of heating surface he had provided. Mr. Siemens could speak confidently as to the mechanical efficiency of action of the respirator, having applied a precisely similar contrivance to a steam engine of his design, some years previously.

Mr. Hawksley contended, that in the caloric engine, the so-called "regenerator" was productive of no mechanical effect, as might be shown, by reducing the engine to a primitive form, so as to get rid of all the complexity consequent upon the employment of valves and flaps, and air under compression. In this form the engine might be assumed, for the sake of illustration, to consist of an upper and a lower cylinder, bearing the proportions, in regard to area, of 1 to 2; the upper cylinder acting as the pump, or receiver, of cooled air, and the lower cylinder as the expansion, or working vessel. It might also be assumed, that the air was expanded and contracted alternately, from 1 volume into 2 volumes, and from 2 volumes into 1 volume, by the operation of the regenerator placed in the connecting pipe of the two cylinders. In this case it would readily be seen, that even if the regenerator should actually operate in the manner alleged, yet that no mechanical effect would be produced, because the space vacated by the motion of the lower piston would be exactly equal to the amount of expansion consequent upon that displacement. Therefore, if in this single case no mechanical effect was produced, *à fortiori* no mechanical effect would result from mere complexity of arrangement, involving no change of principle. The machine, in point of fact, involved a mechanical fallacy, closely allied to the fallacy of perpetual motion, and of quite as simple a character. The motion of the machine created the space to be filled by the air, after its expansion by the restored heat of the regenerator; whereas it had been most erroneously imagined, that the expansion was the cause, rather than the consequence of the motion. Had the design of the machine been scientifically correct, it would have been the wonder of the age,—whereas, by the confusion of cause and effect, (an easy thing to do in a case of this kind), an endeavour had been made, though with great ingenuity, to realize an impossibility. Nevertheless, in contra-

distinction to most attempts of a similar kind, this machine would work. It had motion—it would raise a measurable weight—and it would produce mechanical results. No part of these results were, however, produced by the regenerator, but, on the contrary, simply by the coal consumed under the cylinder bottom, and by which means it was caused to operate in the manner of the earliest attempts to employ the expansion of air as a mechanical agent. Hence he urged, that the caloric-engine possessed no advantages over the air-engine, invented more than twenty years ago by Mr. Parkinson, and afterwards patented by Messrs. Crossley and Parkinson, (the original working model of which engine was exhibited and set in action.) On the contrary, no inconsiderable amount of resistance was occasioned by the friction of the air, in its passage through the meshes of the regenerator, for which a large deduction must be made, from the theoretical effect of the machine, when considered as an ordinary air expansion engine, and in so far, this ponderous machine was inferior to others of a more simple type.

Mr. Pole stated, that the indicator diagram referred to by Mr. Siemens was obtained in the course of a series of experiments on the Cornish engine at the East London Water-works, Old Ford, undertaken by Professor Moseley and himself, at the instance of the British Association, in 1843 and 1844.[1] As the engine in question had been more carefully examined, and its dimensions and capabilities were more accurately known, than perhaps any other of the kind, he conceived great reliance might be placed on the results. The diagram of the steam's action in the cylinder showed, undeniably, that the pressure in expanding, became greater than Marriotte's law would give, and still greater than according to the law assumed to obtain by De Pambour. A large number of experiments tried on other engines, and under different circumstances, had always given the same result. Although, as he had shown in the work alluded to, several causes existed to influence the variation of pressure, the subject was well worthy of further investigation. He had also made some calculations upon the same engine,

[1] *Vide* "Reports of the British Association," 1843 and 1844. Also, "A Treatise on the Cornish Pumping Engine," by William Pole." Part III, 4to; London, Weale, 1848.

with reference to the economical effects of the heat, and came to nearly similar conclusions with Mr. Siemens. He found, that if an engine of that kind, expanding 3½ times, were absolutely perfect, each unit of heat given out by the combustion of the fuel, ought to develop about 134 units of work; but the amount actually produced, in the shape of water raised, was only about 80 units, or 60 per cent. less than the theoretical result. He had endeavoured to discover at what parts of the engine this loss occurred, and had found it might be distributed about as follows:[1]—

Imperfect combustion, and other causes of waste of heat in the boiler	12½
Heat expended in raising the temperature of the feed-water to boiling-point	12½
Friction, imperfect vacuum, air-pump, &c., or power wasted in working the engine . . .	15
	40
Useful effect realized . . .	60
Total calorific power of the fuel .	100

With regard to the general question of the utility of the so-called "regenerator" of the hot-air engine, he conceived it would be found that, as in many other disputed cases, the truth lay between the extremes. He considered that those who asserted, on the one hand, that this appendage was altogether fallacious and useless, were equally wrong with those who insisted, on the contrary, that it was capable of reproducing the power, without any consumption of heat. This might be shown by a consideration of what took place when air was expanded by heat. The quantity of caloric necessary to produce this effect consisted of two distinct parts, each of which performed an entirely separate office in the process. One portion was employed in communicating sensible heat to the mass, *i.e.*, in raising its temperature a certain number of degrees, while the other portion was expended in supplying the latent heat de-

[1] *Vide* "Reports of the British Association," 1843 and 1844. Also, "A Treatise on the Cornish Pumping Engine," by William Pole. Part III., 4to; London, Weale, 1848.

manded by the expansion of bulk of the air; it being understood, according to the usual theory (although differently expressed by the more modern dynamical hypothesis), that a certain quantity of heat became latent in an elastic fluid, whenever its volume was increased. The ratio of these two amounts of heat was known; for (assuming the pressure to remain constant), if the whole quantity expended was represented by 14, the portion used in communicating sensible heat would be about equal to 10, and that absorbed in latent heat equal to 4. Now it might easily be conceived that, by the subsequent application of some apparatus on the principle of the regenerator, the sensible portion of the heat might be abstracted from the heated air; but the other portion, the $\frac{4}{14}$, of latent heat, could only be restored on one condition, namely, by compressing the air again to its former bulk; which would require an absorption of power, precisely the same in amount as had been developed during its expansion; so that, if the whole heat was restored, no power was gained, or if the power was retained, a portion of the heat must be lost. But it was also evident, that if no saving apparatus like the regenerator were applied, not only the latent, but also the sensible heat, a much larger quantity, must be thrown away; and, therefore, in restoring a good part of this to be used again in the next supply of air, the contrivance was undoubtedly beneficial, and might of itself turn the scale of the success, or failure of the machine. Without it, 14 parts of heat must be used for every charge of air; with it, theoretically, only 4 were required. Such, he conceived, was the simplest view of the office of the regenerator, although in practice its action was often complicated by other considerations, and was, therefore, more difficult to trace.

In the Paper so ably rendered by Mr. Manby,—Secretary,—objections had been brought against the alleged advantage of the regenerator, which Mr. Pole could not agree with. The first was, that the escaping air must expand, and so lose temperature. Now, it was not at all necessary to the action of the engine, that the air should leave the cylinder at a density greater than that of the atmosphere, and unless it did, the loss from this cause could not occur. Secondly, M. Cazalat imagined, that the resistance offered to the air, in passing through the meshes of the regenerator must absorb a great deal of power;

but this was merely a question of arrangement and area of passages, and experience had shown that the loss from this cause, under proper management, was scarcely appreciable, M. Cazalat's third objection was derived from his calculations of the temperature of the regenerator, after the passage through it of the hot and cold air respectively. Assuming the air to leave the cylinder at 521·5° (the atmosphere being at 32°) he found that the temperature of the regenerator would be about 277°, and concluded, therefore, that at every stroke 245° of heat would be wasted in the atmosphere, and must be supplied again by the fuel to the entering air. Now, Mr. Pole contended, that this was not a fair way of considering the action of the regenerator, inasmuch as M. Cazalat assumed the air to be mixed with the copper uniformly, in one mass, without taking into consideration the gradation between the hot and cold ends, an arrangement upon which the peculiar beneficial effect of the apparatus entirely depended; the temperature of the outgoing or entering air being determined, in fact, not by the mean temperature of the whole 'Regenerator,' but by that of the last plate it went through, which was very different. The different effect of a similar mass of metal, according as it was disposed in different ways, might easily be shown. Taking the weight of air to be equal to 75 lbs., and the weight of copper to be equal to 1,680 lbs., for convenience of calculation, then, according to M. Cazalat's supposition, if the copper was supposed to be collected in one mass, and the air intimately to be mixed with it, during its passage through the air would escape into the atmosphere with an excess of 245°, and enter the cylinder with an equal deficiency.[1] Now, if the same quantity of copper were divided into eight parts, and arranged in eight separate plates, the result would be much more favourable, the loss in each stroke being reduced from 245° to less than 100°; and by dividing it still further, a still greater economy would result. This consideration should not be lost sight of, in

[1] To ascertain the temperature of a mixture of any two substances; let W and w be their respective weights, C and c their specific heats, and T and t their temperatures before mixing. Their temperature of mixture $=\dfrac{W C T + w c t}{W C + w c}$

the discussion of the merits of the regenerator, as experience had shown it to be of great importance in practice.

It must be allowed, that the general action of caloric, in producing power, was still involved in much obscurity. The heat was often considered in reference to its quantity only, but it was certain also, that its intensity performed a very important part; and, it had even been surmised, that power might be obtained by the reduction of intensity alone, without any change of quantity. An investigation of the subject often produced anomalous cases, very difficult to account for, on the ordinary suppositions. For this reason he thought that any additions to the knowledge of this subject were much to be desired, and he considered that Engineers should look forward with interest to the important communications which M. Regnault, probably the first living authority on such matters, had promised shortly to give to the world.

Mr. W. G. ARMSTRONG concurred in the arguments that had been advanced, both by Mr. Siemens and by Mr. Pole. He could not but think that the regenerator did fulfil an important function in the engine. If with an ordinary cylinder and piston, a charge of heated air were introduced beneath the piston, and then allowed to expand, until it reached an equilibrium with the external medium, the whole available heat would be utilized, and the maximum mechanical effect would be realized in a single operation. Now the same result would virtually be obtained, by stopping the piston at any point short of the ultimate limit, and transferring to a renewed charge of air the heat remaining unutilized in the first charge. Thus the quantity of heat required to make up the full temperature of the second charge would be diminished, to the extent of that which was saved from the first charge. This transference of unutilized heat was performed by the regenerator, and the advantage of its application must be admitted to the extent that it accomplished that object.

Mr. E. WOODS observed, that if the mechanical equivalent of heat was 730 foot-pounds, as it appeared to be, on the average of the experiments by Messrs. Holtzman, Joule, Rankine, and Thompson, alluded to in Mr. Siemens' Paper, then there was still great margin for improvements.

Mr. C. MAY said, that in an engine with a steam-jacket, the steam being confined in a vessel of greater heat than itself, and

being maintained at that temperature by the pressure of steam communicating with the valve, might probably account for the expansive curve showing a greater pressure than the ordinary rule gave.

Mr. E. A. Cowper stated, that in an indicator diagram taken from an engine with no steam-jacket, the expansion curve was a little above the ordinary rule, at the end of the stroke. This, he considered, indicated that the latent and sensible heat of steam together amounted to a greater quantity in high-pressure steam, than in low-pressure steam.

Steam, or gases, in expanding, and so giving out power, lost heat. Part of the sensible heat became latent in the production of power, and this heat could only be recovered, by expending the power already produced, in again condensing the steam back to its original bulk, when the latent heat again became sensible. As, however, the general object was to produce power, this plan could not, of course, be entertained. Therefore, the heat which was sensible, and became latent by the expansion in producing power, was, in fact, the necessary theoretical expenditure of heat required to produce power; and no engine could be made to work by simply supplying the loss of heat by radiation.

He must contend, however, that the sensible heat that was left in the steam, or air, after it had been expanded, could be stored up in plates of metal, or wire gauze, to a considerable extent, and that these plates, so heated, might be used to heat fresh steam, or air, that was about to be used for obtaining power.

Mr. D. K. Clark remarked, that in his experiments on locomotives, he had found that with cylinders in the smoke-box, the curve of expansion was very little above that given by Marriotte's law; but that when the cylinders were exposed, it differed materially. He thought that in the diagram alluded to by Mr. Pole, the steam-jacket had influenced the form of the curve.

Mr. Siemens agreed with Mr. Hawksley's proposition, that an engine of his proportions could not give out any power. The valve between the two cylinders in Ericsson's engine was as necessary as it was between the boiler and cylinder of an ordinary steam-engine, and could not be replaced by the regenerator,

which had a very different office to fulfil. Ericsson's engine might indeed be compared to a steam-engine, in which the boiler was represented by the air-chamber between the two cylinders, and the feed-pump by Ericsson's pumping cylinder. Ericsson had the disadvantage of sacrificing two-thirds of his power to move the pump, but had the advantage of expending no latent heat to form his elastic medium. But it must be borne in mind, that Ericsson had to add to his air a larger amount of sensible heat, of which only a small proportion was really expended in expansion, and the remainder would go to waste, unless it was recovered by the regenerator. Nevertheless, the drawbacks to Ericsson's engine, on account of the great resistance of the pump, the small working pressure, the insufficiency of heating surface, and the working of a piston in a heated cylinder, were so great, that he thought no beneficial results could be expected from it.

Mr. James Stirling, through the Secretary, after alluding to the specification of his brother's, the Rev. Dr. Stirling's, original patent for an air-engine, in 1816, quoted by Mr. Leslie, said that the engine then described was nearly similar to that mentioned in the Paper read to the Institution in June 1845;[1] the only difference was that it had but one air-vessel, with a piston working in the open end of it, and the interior air-tight vessel, or plunger, was worked by a rod, passing through a stuffing-box, in the centre of the piston. In small engines, where the surfaces of the passages between the air-vessel and the plunger bear a large proportion to the volume of air to be acted upon, these surfaces themselves form a considerable portion of the regenerating process; but the specification described this passage as "partially filled with studs, or with wires wound round the plunger, for the purpose of heating and cooling the air more completely, and with less waste;" and a passage filled with wire gauze was actually tried in one of Dr. Stirling's earliest experimental engines.

He constructed an engine of this description, in 1818, for pumping the water from a quarry in Ayrshire, which work it performed very well, until, from the carelessness of the engineman, the bottom of the air-vessel was overheated, and being

[1] *Vide* "Minutes of Proceedings," Inst. C.E., 1845, vol. iv., p. 348.

made of boiler plate, of a flat conical form, it was crushed down by the pressure of the heated air, and rendered useless. This engine did not work to the power expected, and it was feared, at the time, that the air-vessels, for engines of large power, would require to be of enormous size. The undertaking was, therefore, for the moment abandoned.

In 1824, it occurred to him, that the difficulties attending the large working parts might be got over, and the dimensions of the engine greatly reduced, by working with air of a higher density, produced by mechanical compression. This involved the necessity of a closed cylinder, or double-acting engine, with two air-vessels, in order that there might be no means of escape for the compressed air, except by the piston and plunger rods. Having made some experiments with a working model constructed on this principle, these improvements were patented in the beginning of 1827, conjointly by Dr. Stirling and himself. In 1828, an engine on this principle, with a cylinder 26 inches in diameter and 3 feet stroke and about 20 horse-power, was constructed at Messrs. C. Girdwood & Co.'s, Glasgow. It was then found, that the small part of the heat which the 'Regenerator' failed to extract from the air, in its passage to the cold end of the air-vessels, accumulated to such an extent, that the requisite difference of temperature, between the two ends of the air-vessels, could not be kept up, and that the power consequently fell off considerably. This engine was again abandoned; and it was only after overcoming this last difficulty, by the refrigerating apparatus, described in his Paper in 1845, and after testing its efficacy for several months, on a small engine, with a cylinder 3⅝ inches in diameter, and 12 inches stroke, which worked to two-horse power, that the present patent was taken out. A full account of the engines constructed under this patent, was given in the Paper before mentioned. From some difficulties experienced in the management of the furnaces, and in heating the air-vessels equally, the use of the engine there described, was discontinued about a year after the date of the Paper, after it had worked efficiently for more than three years. Still the subject was not abandoned; and he hoped, ere long, to bring it again under the notice of the Institution, with this, he might almost say, its only imperfection, entirely removed.

May 24, 1853.

JAMES MEADOWS RENDEL, President, in the Chair.

The following candidates were balloted for, and duly elected: —William Richard Le Fanu, John Curphey Forsyth, and George Robert Stephenson, as Members.

No. 898.—"A Description of the Newark Dyke Bridge, on the Great Northern Railway." By JOSEPH CUBITT, M. Inst. C.E.

THIS bridge carries the Great Northern Railway across the Newark Dyke, a navigable branch of the Trent, at Newark.

The lines of the railway, and of the navigation, intersect each other at so acute an angle, that although the clear space between the faces of the abutments of the bridge is only 97 feet 6 inches, measured at right angles with the latter, yet the actual clear span of the bridge is 240 feet 6 inches.

There is nothing novel, or peculiar about the abutments. They consist of ordinary brickwork and masonry, and were founded on a bed of strong gravel, by means of coffer-dams.

The railway is carried across the space between the abutments by two separate bridges—one for each line of way—each bridge consisting of two trussed girders, constructed on Warren's principle, as developed by Mr. C. H. Wild, who first brought the principle under the Author's notice, in proportions and details nearly identical, in most particulars, with those ultimately adopted and carried into execution.

Each girder consists of a top tube, or strut of cast-iron, and a bottom tie of wrought-iron links, connected together by alternate diagonal struts and ties of cast and wrought iron respectively, dividing the whole length into a series of equilateral triangles, of 18 feet 6 inches length of side.

These girders rest on the apices of cast-iron A frames, placed on the masonry of the abutments. Each pair is connected by a

horizontal bracing at the top and the bottom, leaving a clear width of 13 feet for the passage of the trains.

The top tube increases in diameter from 1 foot $1\frac{1}{2}$ inch at the ends to 1 foot 6 inches at the centre; the thickness of the metal also increases from $1\frac{1}{2}$ inch at the ends to $2\frac{5}{8}$ inches at the centre. Its total length is 259 feet. It is composed of twenty-nine separate pieces, each piece being accurately turned and fitted at its extremities, so as to insure the exact contact of two metal surfaces of the same area as the cross section of the tube. The pieces are connected together by eight bolts and nuts, passed through small projecting snugs.

Those lengths, or portions of the tube, to which the diagonal struts and ties are connected, are accurately bored, to receive the joint pins, at right angles to the axis of the tube, and are finished with accurately-faced fillets at the ends of the transverse holes.

The lower tie consists of wrought-iron links 18 feet 6 inches in length from centre to centre of the holes, each link being rolled in one piece without any welding. They are of the uniform width of 9 inches, but vary in number and thickness, according to the strains to which each length, or portion of the tie, is subject. Thus—

	Inches.
The 1st, or end lengths near the abutments consist of 4 links	9 × 1
„ 2nd of 4 links	9 × $1\frac{1}{2}$
„ 3rd of 6 „	9 × $1\frac{3}{8}$
„ 4th of 8 „	9 × $1\frac{1}{4}$
„ 5th of 10 „	9 × $1\frac{1}{8}$
„ 6th of 12 „	9 × 1
And the centre of 14 links	9 × $\frac{7}{8}$

The ends of the links are swelled laterally to the width of $16\frac{1}{2}$ inches, for the reception of the joint pins; the swelling is diminished very gradually down to the uniform parallel width of 9 inches. The diameter of the holes, for the joint pins, is $5\frac{1}{2}$ inches; the semi-circumference is about equal to the width of the links, and the thickness of the iron on each side of the hole is $5\frac{1}{2}$ inches.

The diagonal links are of precisely the same form and dimensions as those of the horizontal tie; and are, in like manner, adapted to the strains to which they are subject, by varying their number and thickness.

		Inches.	Area.
The 1st, or end diagonals, consist of 4 links	2 being 2 ,,	$9 \times \frac{15}{16}$ $9 \times \frac{7}{8}$	32·625
2nd of 4 links, each . . .		$9 \times \frac{13}{16}$	29·25
3rd of 4 ,, . . .	2 being 2 ,,	$9 \times \frac{11}{16}$ $9 \times \frac{3}{4}$	25·875
4th of 2 ,, each . . .		$9 \times \frac{13}{16}$	21·375
5th of 2 ,, ,, . . .		$9 \times \frac{15}{16}$	16·875
6th of 2 ,, ,, . . .		$9 \times \frac{3}{4}$	13·5
Aud 7th of 2 ,, ,, . . .		$9 \times \frac{3}{4}$	13·5

The diagonal struts are of cast-iron, the upper end of each forming a jaw, or Y, embracing the top tube, or strut of the girder, and the diagonal links on each side of it. A hole of $5\frac{1}{2}$ inches in diameter is bored through each side of this jaw, and the ends of the holes truly faced. The tube, the links, and both parts of the jaw, are connected by the joint pins, each $5\frac{1}{2}$ inches in diameter, passing through, and accurately fitting, the holes bored for their reception.

From the upper jaw, the struts taper very gradually down to the lower ends. The struts may be generally described as of the form of a Maltese cross in cross section. The lower end of the strut is rectangular in horizontal section, $13\frac{1}{2}$ inches by 5 inches; it is bored to a diameter of $5\frac{1}{2}$ inches, and faced on each side. It is then placed in the centre of the set of links, both diagonal and horizontal, with which it is connected; the diagonal links being placed immediately on each side of it, and the horizontal links beyond them; the joint pin is then passed through the whole.

The horizontal bracing, by which the upper and lower parts of each pair of the trussed girders are connected, consists of a cast-iron pipe extending across from side to side, at each joint pin. This pipe is connected with wrought-iron diagonal ties, each $2\frac{1}{2}$ inches in diameter, and is attached to the upper tube and lower tie, by means of wrought-iron bolts, each $2\frac{1}{2}$ inches in diameter, which are passed transversely through the joint pins, near the inner end.

The links of the lower tie are supported in the middle of their length, by a pair of wrought-iron rods, each $1\frac{1}{8}$ inch in diameter, suspended from the top tube; one being placed on each side of the joint pin. These rods are provided with plates of cast-iron, which, by means of nuts and washers, are tightly brought up to the underside of the links; and the plat-

form of the bridge, which consists of a floor of Memel fir timber 8 inches in thickness, rests upon the upper side of the links.

The end frames are strongly braced transversely by an arched rib of cast-iron above, and by girders, with bracket pieces, below, for the purposes of preventing any lateral, or rocking motion. All the meeting surfaces are accurately planed, and all the bolts are fitted truly in their holes.

In a recess, at the top of each frame, is placed, upon a planed surface, a block of gun-metal 10 inches square, and upon these blocks the ends of the top tubes of the bridge rest and the entire weight of the girders is taken.

The weight of iron in the two trusses and in the top and bottom bracing of one of the bridges, is 244 tons 10 cwt.; of this, 138 tons 5 cwt. consists of cast-iron and 106 tons 5 cwt. of wrought-iron; while the weight of the platform, the handrail and the moulded cornice, is 50 tons; thus making the total weight of each bridge 294½ tons.

The trusses are so arranged, that all compressive strains are taken by the cast-iron, and all tensile strains by the wrought-iron; the strains, in all cases, in the direction of the length are of the respective parts, and all cross strain is avoided. The parts are so proportioned, that when loaded with a weight equal to one ton per foot run, which considerably exceeds the weight of a train of the heaviest locomotive engines in use on the Great Northern, or on any narrow-gauge line, no tensile, or compressive strain on any part, exceeds five tons per square inch of section.

The bridge was subjected to the following tests:—

1st. By placing upon it a weight equal to 1½ ton per foot run of the entire length between the points of suspension	=	390 tons.
Plus the weight of the timber, platform rails, bolts, &c.		56 ,,
In all		446 ,,
2nd. By placing upon it a weight equal to 1 ton per foot between the points of suspension being .	=	260 tons.
Plus the platform as above		56 ,,
In all		316 ,,

3rd. By running over it a train of waggons, loaded up to a weight of 1 ton per foot run, for the length of the floor, or plat-

form of the bridge, when fixed complete, in its place; the moving weight being 240 tons.

In the first experiment, the weight was distributed equally among the thirteen compartments, the whole being sustained on screw-jacks, clear of the part of the bridge on which it was to rest. It was then lowered first on the two end compartments, till it rested on the lower tie of the bridge, and the deflection read off at each triangle.

The compartments next the two end ones were then loaded, and similar readings taken, and so on through the whole number of compartments, the deflection being read at each point, on every addition of weight.

The annexed table gives the result of each addition to the load:

TABLE No. 1.

—	One Triangle at each end loaded.	Two Triangles at each end loaded.	Three Triangles at each end loaded.	Four Triangles at each end loaded.	Five Triangles at each end loaded.	Six Triangles at each end loaded.	All Triangles loaded.
	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
Depression of North A, Frame .	·000	·000	·020	·020	·030	·030	·030
Deflection in 1st Triangle . .	·020	·030	·060	·100	·140	·150	·190
,, 2nd ,, . .	·015	·040	·070	·140	·160	·240	·275
,, 3rd ,, . .	·030	·070	·150	·190	·240	·330	·370
,, 4th ,, . .	·030	·070	·140	·210	·310	·400	·490
,, 5th ,, . .	·020	·075	·145	·210	·310	·430	·545
,, 6th ,, . .	·C30	·085	·160	·220	·330	·450	·575
,, 7th ,, (Centre)	·010	·075	·140	·220	·320	·440	·580
,, 8th ,, . .	·010	·075	·140	·220	·320	·450	·550
,, 9th ,, . .	·010	·060	·140	·220	·320	·430	·515
,, 10th ,, . .	·020	·070	·130	·190	·280	·400	·475
,, 11th ,, . .	·010	·050	·100	·160	·220	·315	·390
,, 12th ,, . .	·015	·060	·100	·120	·175	·255	·290
,, 13th ,, . .	·010	·050	·060	·070	·100	·140	·175
Depression at South A, Frame .	·000	·000	·000	·000	·015	·020	·020

In the second experiment, the load was equally divided, and arranged as in the first case, for lowering upon each compartment, separately.

In this case, the loading commenced at one end compartment, then the second, the third, and so on consecutively, till the whole weight had been put on.

The bridge was then relieved of its load, by lifting it off in the same order in which it had been imposed, and a reading taken at every triangle, on the addition, and also on the removal, of each portion of the load, thus getting the effect of the passage of a train of the aggregate weight of 316 tons.

The subjoined table gives the deflections obtained by this experiment:—

TABLE No. 2.

—	Three Triangles at South End loaded.	Five Triangles at South End loaded.	Seven Triangles at South End loaded.	Nine Triangles at South End loaded.	Eleven Triangles at South End loaded.	All the Triangles loaded.	Load removed from two Triangles at South End.	Load removed from four Triangles at South End.	Load removed from six Triangles at South End.	Load removed from eight Triangles at South End.	Load removed from ten Triangles at South End.	All the Load removed.
	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
Depression on North A Frame	·000	·000	·000	·000	·030	·030	·030	·030	·030	·030	·030	·000
Deflection at 1st Triangle	·000	·000	·020	·050	·060	·100	·080	·050	·050	·030	·020	·000
„ 2nd „	·000	·010	·040	·100	·130	·170	·160	·120	·100	·030	·000	·000
„ 3rd „	·000	·030	·080	·150	·180	·230	·220	·200	·140	·070	·040	·000
„ 4th „	·010	·030	·120	·190	·250	·290	·260	·250	·135	·100	·040	·000
„ 5th „	·020	·070	·160	·250	·300	·320	·280	·275	·200	·130	·040	·000
„ 6th „	·000	·070	·170	·260	·320	·330	·320	·285	·200	·110	·040	·000
„ 7th „ (Centre)	·020	·090	·200	·270	·330	·360	·330	·290	·190	·105	·040	·000
„ 8th „	·040	·120	·210	·290	·340	·380	·340	·285	·190	·100	·050	·000
„ 9th „	·030	·120	·180	·240	·290	·310	·300	·230	·150	·070	·010	·000
„ 10th „	·010	·080	·140	·200	·290	·270	·290	·170	·100	·020	·000	·000
„ 11th „	·030	·070	·120	·170	·190	·210	·200	·140	·080	·020	·000	·000
„ 12th „	·000	·040	·080	·100	·120	·140	·115	·090	·050	·000	·000	·000
„ 13th „	·000	·000	·020	·050	·050	·060	·060	·040	·000	·000	·000	·000
Depression at South A Frame	·000	·000	·000	·020	·020	·030	·030	·030	·000	·000	·000	·000

In this experiment, the compression of the top tube, and the exteusion of the lower tie, were increased, and the former was found to be 13-16ths of an inch; and the latter 1 inch.

The above experiments were made on the premises of the Contractors, Messrs. Fox and Henderson, the bridge having been put together for the purpose.

The third experiment was made after the bridge was fixed complete in its place. A train of waggons, loaded up to one ton per foot run of the bridge, was, in the first instance, moved on to the bridge, till the leading waggon reached the centre; and the deflection was then measured at each triangle. The train was then moved on, till it occupied the entire length of the bridge, and the deflections at each point again measured. The train was then moved on till the last waggon reached the centre and the deflections again taken as before.

The following table gives the results thus obtained :—

TABLE No. 3.

—	North half of Bridge loaded.	The whole length of the Bridge loaded	South half of Bridge loaded.
	Inches.	Inches.	Inches.
Deflection at 1st Triangle . .	$\frac{3}{8}$	$\frac{11}{16}$	$\frac{11}{16}$
„ 2nd „ . .	$\frac{11}{16}$	$1\frac{5}{16}$	1
„ 3rd „ . .	1	$1\frac{3}{4}$	$1\frac{3}{8}$
„ 4th „ . .	$1\frac{1}{4}$	$2\frac{1}{4}$	$1\frac{9}{16}$
„ 5th „ . .	$1\frac{1}{2}$	$2\frac{1}{2}$	$1\frac{5}{8}$
„ 6th „ . .	$1\frac{1}{2}$	$2\frac{9}{16}$	$1\frac{1}{2}$
„ 7th „ . .	$1\frac{5}{8}$	$2\frac{3}{4}$	$1\frac{5}{8}$
„ 8th „ . .	$1\frac{5}{8}$	$2\frac{9}{16}$	$1\frac{1}{2}$
„ 9th „ . .	$1\frac{1}{2}$	$2\frac{3}{8}$	$1\frac{1}{4}$
„ 10th „ . .	$1\frac{3}{8}$	2	$1\frac{1}{16}$
„ 11th „ . .	$\frac{15}{16}$	$1\frac{7}{16}$	$\frac{3}{4}$
„ 12th „ . .	$\frac{9}{16}$	$\frac{7}{8}$	$\frac{7}{16}$

The deflection caused by two heavy goods engines passing over the bridge, was $2\frac{1}{8}$ inches in the centre; and it was found to be the same, whether the engines passed over rapidly, or slowly.

The deflection produced by passing a train, consisting of five of the heaviest class of engines in use on the Great Northern Railway, was $2\frac{1}{2}$ inches in the centre.

The Paper is illustrated by three lithographic drawings, Nos. 4625-6 and 7, from which Plate 4 has been compiled.

Sir CHARLES FOX, remarked that, the great advantage of this mode of construction consisted in being able to frame it complete at the manufactory, to mark and take it to pieces, so as to obviate the necessity for sending skilled workmen for its erection in its place, as this could then be effected by ordinary labourers. Notwithstanding the convenience of erecting this kind of girder, he should prefer one with a continuous web of plate iron, when placed in a position exposed to accident, such as a carriage getting off the line, as he thought it would bear a blow with less danger of being destroyed. The proper sizes for the top and bottom tables of a girder could be calculated with precision, but the best mode of forming the connection between them was a matter for further investigation and experiment; at present, he was disposed to prefer it being done by a continuous web without perforations.

Mr. BIDDER, V.P., considered that the question for discussion was, the relative advantages of the Warren girder, as compared with girders constructed on other principles. Now he was prepared to maintain, that however well made this particular bridge might be, this form of girder was certainly not superior, nor even equal, to an ordinary tubular beam. The theory of the girder was now well understood. The forces applicable to the two systems were identical, and the whole question resolved itself into what was the most convenient and economical mode of filling in between the top and bottom tables. He thought the sides of the tubular girder, as well as forming the connection between the top and bottom, contributed to the stability of the bridge; and that if the separate plates were well riveted together, each side might be taken as one entire plate. With the Warren girder, the failure of one piece would hazard the destruction of the whole bridge; and an accident like that which occurred to the tubular girder at Ferry Bridge would have jeopardized the entire structure. Again, with a tubular beam, the bottom tube formed a platform, and added greatly to the stability and strength of the bridge.

He believed that the great number of bearings in the Warren girder must cause motion, and that the deflection, as stated, was double what it would have been with a tube. As to convenience of erecting by unskilled labour, he could conceive nothing easier than a tubular girder; the plates were all ready punched, there

could be no difficulty in assembling them, and they were in a convenient form to be transported. Where there was a series of openings, the tubular bridge, by its continuity over the piers, was certainly superior to any other.

As to the relative cost, this was a question of workmanship. He much doubted whether the parts of the Warren girder could be put together at a less rate than mere riveting, for great care and skill would be required in their adjustment. The Newark Dyke bridge had cost, he understood, £20 per ton, which, considering the price of iron at the time was quite as much as a tubular bridge would have cost.

Mr. VIGNOLES said, the Newark Dyke bridge was so successful, that it must be received as a practical illustration and elucidation of the soundness of the principle of the Warren girder. He thought the principles involved had opened up a new field for consideration; and that the profession was greatly indebted to the Author of the Paper, for affording an opportunity for testing them on a large scale, as well as for sending an account of the works to the Institution; also to Sir Charles Fox, as the Contractor for the works, and to Mr. C. H. Wild, for working out the dimensions of the several parts. As to the weight of this bridge, he believed, that by substituting wrought for cast iron, and altering the dimensions of some of the parts, other girders on the same principle might be made lighter.

Circumstances had necessitated his examining, in detail, the principles of the Warren girder, with a view of ascertaining its applicability for large spans. He had not adopted it, and he did not now recommend it; but still he thought it had merits. For Russia, or other cold climates, he considered it inapplicable, in consequence of its being partly composed of cast iron. In some hilly countries, where the means of internal communication were not good, it might be found useful, on account of the facility with which the separate parts could be transported. He had found much damage done to boiler plates, in transport, when the rivet-holes were punched beforehand, and a great deal of patching was required when they came to be used. He thought it had been admitted, that the strength of a tubular bridge was due to the top and bottom and not to the sides, which were chiefly for forming the connection. Where there

was more than one span, the advantage of continuity was certainly in favour of the tube. He hoped shortly to be able to show, that by other modes of connecting the top and bottom, he should be able to save one-half the weight of the tube, preserving, of course, equal strength.

Captain W. S. Moorsom coincided in the remarks which had been made, as to the number of points of connection that must always exist, and the nicety of adaptation that would always be required, in beams of the kind under discussion. In his opinion, if the lattice system had been used, the cost would have been less, whilst the security would have been greater.

Mr. R. Stephenson, M.P., V.P., would be glad to offer a few remarks on some points not touched upon by preceding speakers. Treating the girders of the Newark Dyke bridge as ordinary beams, there would be little difference of opinion, that the top resisted compression, and the bottom extension. The question then was, what were the comparative merits of the close sides of the tube, the open sides of this girder, and the openings of the lattice. In the close side of the tube no one part bore more than its neighbour; there was, in fact, a diffusion of pressure, whilst in a Warren girder there was a concentration of pressure He believed diffusion to be the best; others thought concentration the best. The plates of a tube formed an infinite number of ties, conveying the compressive forces of the top to the tensile forces of the bottom. The strains were the same in amount and direction in all kinds of beams, but they were more equally diffused in a tube. In a Warren girder, the tendency of the struts was to break in the centre; and in order to prevent that effect tension bars, or lateral ties, were applied at right angles. As the struts and ties were increased in number, the lattice form was arrived at, which he considered to be a good approach to a tube, but the material was not quite so well applied. If the apertures on each side the strut were filled in by plates, the strut was supported, and the materials were retained in the position where they could be most efficiently employed. He did not think the struts, in the Warren girder, were so placed as to derive the utmost advantage from the metal. The ties were equally good in all systems, but the struts were the dangerous points.

As to the comparative convenience and economy of putting tubes together and erecting Warren girders abroad, he believed the latter would require as much care in fitting, as the former would in riveting. He was about to send out four, or five boiler-makers to superintend the riveting of the tubes for the bridge over the Nile. The actual riveting would be done by the Arabs under their direction, and he felt convinced, that they would do it as well as they had already laid the permanent way of the railway. There could be no doubt, that the plates of a tubular bridge were more portable, than the cast-iron struts and ties of the Warren-girders.

Mr. EATON HODGKINSON remarked, that he doubted very much, whether by any system one-half the weight of metal at present used for tubular bridges could be dispensed with, provided the same strength was retained. He did not like riveting the bottom of a tube, as it lessened the power to resist tension very much. In some experiments which he had made for Mr. Fairbairn, and an account of which that gentleman had given in the Transactions of the British Association, common riveting gave, at the utmost, only $\frac{6}{10}$ths of the strength of the materials, when under tension. He preferred using wrought iron not riveted in the bottom, and adding cast iron to the top, as it was a good auxiliary to resist compression.

Mr. RENDEL,—President,—said, Mr. Eaton Hodgkinson's experiments had settled the question of the top and bottom sections, but there was still much to be considered. He had recommended the employment of Warren's girders in India, for spans under 80 feet, because they could be easily put together, as they required no riveting. They were to be made entirely of wrought iron, and in pieces of a size convenient to handle, in erecting, and easy of transport. Had tubular bridges been used for this span, the plates would have been so thin, that they would soon have been destroyed in that country, by corrosion, otherwise he should certainly have recommended them.

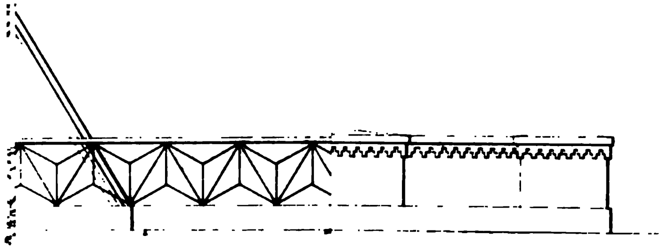
In concluding the business of the Session, the President expressed his regret, that the time at the disposal of the meeting had not permitted Mr. Henderson's Paper "On Ocean Steamers," nor Mr. J. Leslie's "On an Incline Plane for

Canals," to be entered upon, but they would be brought forward early next season.

May 31, 1856.

The Session was concluded by a Conversazione, at which the President received the Members of the Institution, and a large circle of distinguished visitors, when the rooms were profusely decorated by works of art, with a very good display of interesting mechanical models.

PLATE 4.



INDEX

TO THE

MINUTES OF PROCEEDINGS,

1852–53.

A.

B.

N.

O.

P.

R.

S.

LONDON:
PRINTED BY W. CLOWES AND SONS, STAMFORD STREET,
AND CHARING CROSS.